(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
5 February 2004 (05.02.2004)

PCT

(10) International Publication Number
WO 2004/011647 A1

(51) International Patent Classification[7]: C12N 15/11, A61K 31/711

(21) International Application Number: PCT/US2003/023104

(22) International Filing Date: 25 July 2003 (25.07.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/398,605 26 July 2002 (26.07.2002) US

(71) Applicant *(for all designated States except US)*: **CHIRON CORPORATION** [US/US]; 4560 Horton Street, Emeryville, CA 94608 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **HAN, Jang** [US/US]; c/o Chiron Corporation, 4560 Horton Street, Emeryville, CA 94608 (US). **SEO, Mi Young** [US/US]; c/o Chiron Corporation, 4560 Horton Street, Emeryville, CA 94608 (US). **HOUGHTON, Michael** [US/US]; c/o Chiron Corporation, 4560 Horton Street, Emeryville, CA 94608 (US).

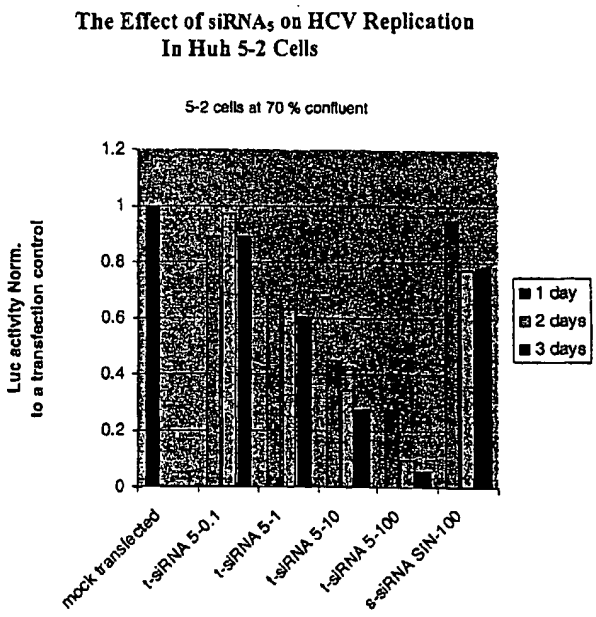
(74) Agents: **PEET, Richard, C.** et al.; Foley & Lardner, Washington Harbour, 3000 K Street, N.W., Suite 500, Washington, D.C. 20007-5143 (US).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO,

[Continued on next page]

(54) Title: MODIFIED SMALL INTERFERING RNA MOLECULES AND METHODS OF USE



(57) Abstract: The present invention provides double-stranded RNA molecules that mediate RNA interference in target cells, preferably hepatic cells. The invention also provides double-stranded RNA molecules that are modified to be resistant to nuclease degradation, which inactivates a virus, and more specifically, hepatitis C virus (HCV). The invention also provides a method of using these modified RNA molecules to inactivate virus in mammalian cells and method of making modified small interfering RNAs (siRNAs) using human Dicer.

WO 2004/011647 A1

SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

- *with international search report*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Modified Small Interfering RNA Molecules and Methods of Use

BACKGROUND OF THE INVENTION

The present invention relates to the field of nucleic acid detection and to the phenomenon of RNA silencing, or RNA interference (RNAi). RNA silencing constitutes a phenomenon wherein non-coding RNA molecules mediate specific gene suppression in an organism. In nature, the phenomenon protects an organism's genome from foreign, invading nucleic acids such as transposons, trangenes and viral genes.

The introduction of double-stranded RNA (dsRNA) into a cell triggers RNA silencing, which then degrades endogenous mRNA corresponding to the dsRNA. RNA silencing pathways involve a conversion of dsRNA into short interfering RNAs (siRNAs) that direct ribonucleases to homologous mRNA targets (Baulcombe *et al.*, 2001). An enzyme called Dicer processes the dsRNA into siRNAs, which are 20-25 nucleotides long. The siRNAs then assemble into endoribonuclease-containing complexes known as RNA-induced silencing complexes (RISCs). Subsequently, the siRNAs guide the RISCs to complementary RNA molecules, where the RISCs cleave and destroy the target mRNA. Small amounts of dsRNA can silence a large amount of target mRNA due to an amplification component of RNA silencing (Fire *et al.*, *Nature*, 391:806-811 (1998)).

The first evidence that dsRNA produces efficient gene silencing through RNAi came from studies on the nematode *Caenorhabditis elegans* (Fire *et al.*, *Nature*, 391:806-811 (1998) and U.S. Patent No. 6,506,559). Later studies in the fruit fly *Drosophila melanogaster* demonstrated that RNAi is a multi-step mechanism (Elbashir *et al.*, *Genes Dev.*, 15(2): 188-200 (2001)).

Although dsRNA can mediate gene-specific interference in mammalian cells (Wianny, F. and Zernicka-Goetz, M., Nature Cell Biol. 2:70-75 (2000) Svoboda, P. *et al.*, Development 17:4147-4156 (2000)), the use of RNAi in mammalian somatic cells is often limited by a triggering of dsRNA-dependent protein kinase (PKR), which inactivates the translation factor eIF2a, causes a generalized suppression of protein synthesis and often times causes apoptosis (Gil, J. and Esteban, M., Apoptosis 5:107-114(2000)).

Recently, siRNA of approximately 21 or 22 base pairs in length, corresponding to targeted RNA or DNA sequences, were shown to disrupt the expression of the targeted sequences in mammalian cells (Elbashir, S.M., *et al.*, Nature 411: 494-498 (2001)). However, it is not clear that all RNA or DNA sequences of a mammalian cell's genome are susceptible to siRNA. It is also uncertain that every mammalian cell type possesses the necessary machinery for effectuating gene-specific suppression using siRNA. Further, siRNA is of limited use for at least two reasons: (a) the transient nature of the suppression effect seen in cells where the siRNA has been administered, and (b) the necessity for chemical synthesis of siRNAs before their use (Tuschl, T., Nature Biotech., 20: 446-448 (2002)). Also, since siRNAs are unstable *in vivo*, their long-term effectiveness is limited.

An invention that addresses these challenges will improve the utility of RNAi for treating human disease at the level of nucleic acid activity. In particular, such an invention will make RNAi a more practical therapy for viral infections, such as infections with HCV. Current therapies for such viral infections are very limited, and tend to have poor response rates.

SUMMARY OF THE INVENTION

The present invention provides double-stranded RNA (dsRNA) molecules that mediate RNA interference in target cells. In particular, it provides small interfering RNAs (siRNAs) that inhibit viral replication in infected cells. Preferred dsRNA molecules of the invention correspond to hepatitis C virus (HCV) nucleic acids, and inhibit replication of HCV in hepatic cells.

In another aspect, the invention provides modified dsRNA, including siRNA, molecules that are protected against nuclease degradation, but are able to inhibit viral replication in mammalian cells.

The invention also provides methods of inhibiting viral replication in infected cells by administering dsRNA or siRNA molecules. Modified dsRNA and siRNA molecules are particularly useful in these methods, as they are nuclease resistant, yet retain the biological activity of being able to inhibit viral replication by targeting an RNA sequence in a virus.

The invention further provides a method of making modified siRNAs that target a viral RNA or DNA sequence. The method comprises preparing a dsRNA fragment that contains at least one modified ribonucleotide in at least one strand, and cleaving the dsRNA fragment with Dicer enzyme, resulting in more than one modified siRNA.

Other objects, features and advantages of the invention will become apparent from the following detailed description. The description and specific examples indicate preferred embodiments, but should not be considered limiting, as various modifications within the scope of the invention will become apparent to those skilled in the art from the detailed description. Further, the examples demonstrate the principle of the invention, but cannot be expected to specifically illustrate all useful applications.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 depicts the sequence and secondary structure of the 5' UTR from the HCV genome. It also provides specific sequences of siRNAs for inducing RNAi toward HCV in hepatic cells.

Fig. 2 provides sequences for several HCV-specific siRNAs that are useful for inducing RNAi toward HCV in hepatic cells. Each HCV-specific siRNA is identified by the designation provided in the first column.

Fig. 3 shows the nucleotide sequence of the SARS coronavirus.

Fig. 4 is a schematic representation of the open reading frames of the SARS coronavirus.

Fig. 5 depicts a subgenomic HCV replicon contained in the hepatoma cell line Huh 7, which was used to test the efficacy of siRNA in human liver cells.

Fig. 6 depicts the dose response of normalized luciferase activity in Huh-7 cells containing the subgenomic HCV replicon (5-2 line), that were administered different concentrations of siRNA5. Luciferase activity, which was measured at 1, 2 and 3 days post-transfection, fell with increasing doses of siRNA. The luciferase assay was performed using a Luciferase assay system available from Promega Corp. (Madison, WI), according to the manufacturer's instructions.

Fig. 7 depicts the sequence specificity of siRNA5 for inducing HCV-directed RNAi in Huh-7 liver cells.

Fig. 8 demonstrates that siRNA5 is not toxic to Huh-7 cells. ATPase levels were assayed using an ATPase assay kit available from Promega Corp. (Madison, WI), according to the manufacturer's instructions.

Fig. 9 depicts the effects of siRNA5 on HCV replication in 21-5 cells (Huh-7 cells containing full-length HCV), as measured by RNA assay. RNA levels were assayed using a TaqMan™ RNA kit (F. Hoffman La-Roche, Switzerland), according to the manufacturer's instructions. Values are normalized.

Fig. 10 demonstrates that siRNA5 does not affect the viability of Huh 5-2 cells. Specifically, mRNA encoding GAPDH, an enzyme essential to glycolysis was measured in Huh 5-2 cells transfected with siRNA5 or GAPDH-specific siRNA. The graph demonstrates that siRNA5 did not affect RNA levels of GAPDH. GAPDH was measured using a TaqMan™ RNA kit (F. Hoffman La-Roche, Switzerland), according to the manufacturer's instructions. Values are normalized.

Fig. 11 depicts a dose response of normalized luciferase activity in Huh 7 cells containing a subgenomic HCV replicon (5-2 line) that were administered different concentrations of 2'-fluoro-siRNA (2'-F-GL2), which targets the fruit fly luciferase gene. Luciferase activity, which was measured at 2 days post-transfection, fell with

increasing doses of siRNA. The luciferase assay was performed using a Firefly Luciferase kit (Promega Corp., Madison, WI), according to the manufacturer's instructions.

Fig. 12 demonstrates an inhibition of luciferase activity in 5-2 cells using the siRNA Chol-GL2 in the absence of liposomes.

Fig. 13 depicts an autoradiograph of 5'-labeled siRNA duplexes separated by PAGE, and shows the stability of 2'-fluoro-modified siRNA (2'-F-GL2) incubated in human serum for up to 10 days. The siRNA duplexes were subjected to incubation with human serum and analysis by 20% PAGE. The composition of the lanes is as follows: Lanes 1, 11 and 21: ^{32}P-end labeled siRNA alone; Lanes 2-10, 12-20 and 22-25: siRNA incubated with human serum. Lanes 2 & 12, 1 min ; Lanes 3 & 13, 5 min ; Lanes 4 & 14, 15 min ; Lanes 5 & 15, 30 min ; Lanes 6 & 16, 1 hr ; Lanes 7 & 17, 2 hr ; Lanes 8 & 18, 4 hr ; Lanes 9 & 19, 8 hr ; Lanes 10 & 20, 24 hr ; Lanes 22, 24 hr ; Lanes 23, 48 hr ; Lanes 24, 120 hr ; Lanes 25, 240 hr incubation, respectively.

Fig. 14 demonstrates the use of recombinant human dicer to convert fluorinated dsRNA into 2'F-siRNA. The composition of the lanes is as follows: Lane 1: size marker, λ\HindIII+φX174\HaeIII; Lane 2: ribo/ribo homoduplex RNA; Lane 3: ribo/2'-F heteroduplex RNA; Lane 4: 2'-F/ribo heteroduplex RNA; Lane 6: size marker, 10bp DNA ladder; Lane 7: ribo/ribo homoduplex siRNA; Lane 8: ribo/2'-F heteroduplex siRNA; Lane 9: 2'-F/ribo heteroduplex siRNA; Lane 10: 2'-F/2'-F homoduplex siRNA.

Fig. 15 shows a dose response of normalized luciferase activity in Huh-7 cells containing the subgenomic HCV replicon (5-2 line) to HCV-specific siRNAs. Luciferase activity fell with increasing doses of each siRNA.

Fig. 16 shows that cholesterol shows a dose response of normalized luciferase activity in Huh-7 cells containing the subgenomic HCV replicon (5-2 line) to cholesterol-modified GL2 siRNA.

DETAILED DESCRIPTION OF THE INVENTION

The present invention provides dsRNA molecules that are about 10 to about 30 nucleotides long, and that mediate RNA interference in target cells. Preferably, the inventive molecules are chemically modified to confer increased stability against nuclease degradation, but retain the ability to bind to target nucleic acids.

As used herein, "RNA interference" (RNAi) refers to sequence-specific or gene specific suppression of gene expression (protein synthesis) that is mediated by siRNA, without generalized suppression of protein synthesis. While the invention is not limited to a particular theory or mode of action, RNAi may involve degradation of messenger RNA (mRNA) by an RNA-induced silencing complex (RISC), preventing translation of the transcribed mRNA. Alternatively, it may involve methylation of genomic DNA, which shunts transcription of a gene. The suppression of gene expression caused by RNAi may be transient or it may be more stable, even permanent.

"Gene suppression", "targeted suppression", "sequence-specific suppression", "targeted RNAi" and "sequence-specific RNAi" are used interchangeably herein. Furthermore, sequence-specific suppression, as used herein, is determined by separately assaying levels of the protein targeted for suppression in cells containing the siRNA (experimental cells) and in cells not containing the identical siRNA (control cells), then comparing the two values. Experimental and control cells should be derived from the same source and same animal. Also, control and experimental cells used in determining the level or quantity of gene suppression should be assayed under similar, if not identical, conditions.

RNA is a polymer of ribonucleotides, each containing the sugar ribose in association with a phosphate group and a nitrogenous base (typically, adenine, guanine, cytosine, or uracil). Like its cousin, DNA, RNA can form complementary hydrogen bonds. Therefore, RNA may be double-stranded (dsRNA), single-stranded (ssRNA) or double-stranded with a single-stranded overhang. Common types of RNA include messenger RNA (mRNA), transfer RNA (tRNA), ribosomal RNA (rRNA), short interfering RNA (siRNA), micro RNA (miRNA) and small hairpin

RNA (shRNA), each of which plays a specific role in biological cells. As used herein, the term "RNA" includes all of these.

"Small interfering RNA" (siRNA) refers to double-stranded RNA molecules from about 10 to about 30 nucleotides long that are named for their ability to specifically interfere with protein expression. Preferably, siRNA molecules are 12-28 nucleotides long, more preferably 15-25 nucleotides long, still more preferably 19-23 nucleotides long and most preferably 21-23 nucleotides long. Therefore, preferred siRNA molecules are 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27 28 or 29 nucleotides in length.

The length of one strand designates the length of an siRNA molecule. For instance, an siRNA that is described as 21 ribonucleotides long (a 21-mer) could comprise two opposite strands of RNA that anneal together for 19 contiguous base pairings. The two remaining ribonucleotides on each strand would form an "overhang." When an siRNA contains two strands of different lengths, the longer of the strands designates the length of the siRNA. For instance, a dsRNA containing one strand that is 21 nucleotides long and a second strand that is 20 nucleotides long, constitutes a 21-mer.

siRNAs that comprise an overhang are desirable. The overhang may be at the 5' or the 3' end of a strand. Preferably, it is at the 3' end of the RNA strand. The length of an overhang may vary, but preferably is about 1 to about 5 bases, and more preferably is about 2 nucleotides long. Preferably, the siRNA of the present invention will comprise a 3' overhang of about 2 to 4 bases. More preferably, the 3' overhang is 2 ribonucleotides long. Even more preferably, the 2 ribonucleotides comprising the 3' overhang are uridine (U).

siRNAs of the present invention are designed to interact with a target ribonucleotide sequence, meaning they complement a target sequence sufficiently to bind to the target sequence. Preferably the target ribonucleotide sequence derives from a disease producing agent or pathogen. More preferably, the target ribonucleotide sequence is in a virus genome of an RNA virus or a DNA virus. Even more preferably, the virus is selected from the group consisting of hepatitis C virus

(HCV), hepatitis A virus, hepatitis B virus, hepatitis D virus, hepatitis E virus, Ebola virus, influenza virus, rotavirus, reovirus, retrovirus, poliovirus, human papilloma virus (HPV), metapneumovirus and coronavirus.

Hepatitis C virus (HCV) is a highly preferred virus target. Figure 1 and Figure 2 disclose the nucleic acid sequences for several HCV-specific siRNA molecules. Among those shown, siRNA5, siRNAC1, siRNAC2, siRNA5B1, siRNA5B2, and siRNA5B4 have shown particularly good activity, and therefore are highly preferred. siRNAs at least 80%, 90%, or 95%, identical to these highly preferred siRNAs also constitute part of the invention..

Another preferred virus target is the coronavirus, which is associated with upper respiratory infections in humans and recently has been linked with SARS (severe acute respiratory syndrome). Coronavirus has the largest known RNA virus genome, 32 kilobases long, and its genome is composed of positively stranded RNA. (See Figure 5) Each coronavirus mRNA has a 5'-end leader sequence of 60 to 80 nucleotides that is identical to the 5'-UTR of genomic RNA approximately 200 nucleotides long. (See Figure 6) These sequences are highly conserved, and therefore, provide an excellent source of target sequences for which siRNAs. See Fundamental Virology, 3rd Ed., Chapter 18, p. 541-560 (Eds. Fields, Knipe and Howley), Lippincott-Raven (1995). In one embodiment, the entire leader sequence (nucleotides 1-72) is targeted. In another embodiment, one or more sections of the leader sequence is targeted. In a preferred embodiment, nucleotides 64-72 (TAAACGAAC) of the leader sequence are targeted. siRNA targeted to the coronavirus may be modified or unmodified.

In one embodiment, the invention provides an siRNA molecule comprising a ribonucleotide sequence at least 80% identical to a ribonucleotide sequence from a target agent or virus. Preferably, the siRNA molecule is at least 90%, 95%, 96%, 97%, 98%, 99% or 100% identical to the ribonucleotide sequence of the target agent or virus. The target can be the entire viral genome, a primary transcript, an open reading frame, or any portion of these. Most preferably, an siRNA will be 100% identical to the nucleotide sequence of a target agent or virus. However, siRNA molecules with insertions, deletions or single point mutations relative to a target may

also be effective. Tools to assist siRNA design are readily available to the public. For example, a computer-based siRNA design tool is available on the internet at www.dharmacon.com.

By way of example, a polynucleotide having a nucleotide sequence at least 95% "identical" to a reference nucleotide sequence means that the polynucleotide's sequence may include up to five point mutations per 100 nucleotides of the reference nucleotide sequence, or 1 point mutation per 20 nucleotides. In other words, to obtain a polynucleotide having a nucleotide sequence at least 95% identical to a reference nucleotide sequence, up to 5% of the nucleotides in the reference sequence may be deleted or substituted with another nucleotide, or a number of nucleotides up to 5% of the total nucleotides in the reference sequence may be inserted into the reference sequence. These mutations of the reference sequence may occur at the 5' or 3' terminal positions of the reference nucleotide sequence or anywhere between those terminal positions, interspersed either individually among nucleotides in the reference sequence or in one or more contiguous groups within the reference sequence.

As a practical matter, whether any particular nucleic acid molecule is at least 90%, 95%, 96%, 97% 98%, 99% or 100% identical to the ribonucleotide sequence of a target agent or virus can be determined conventionally using known computer programs such as the Bestfit program (Wisconsin Sequence Analysis Package, Version 8 for Unix, Genetics Computer Group, Madison, WI). Bestfit uses the local homology algorithm of Smith and Waterman (Advances in Applied Mathematics 2:482-489 (1981)) to find the best segment of homology between two sequences. When using Bestfit or any other sequence alignment program to determine whether a particular sequence is, for instance, 95% identical to a reference sequence according to the present invention, the parameters are set, of course, such that the percentage of identity is calculated over the full length of the reference ribonucleotide sequence and that gaps in homology of up to 5% of the total number of ribonucleotides in the reference sequence are allowed.

The present invention also includes siRNA molecules that have been chemically modified to confer increased stability against nuclease degradation, but retain the ability to bind to target nucleic acids that may be present in cells. In the

case where a target RNA is virus-specific, the modified siRNAs are able to bind to the virus specific RNAs or DNAs, thereby inactivating the virus.

A modified siRNA of the present invention comprises a modified ribonucleotide, and is resistant to enzymatic degradation, such as RNase degradation, yet retains the ability to inhibit viral replication in a cell containing the specific viral target RNA or DNA sequences. The siRNA may be modified at any position of the molecule so long as the modified siRNA binds to a target sequence and is resistant to enzymatic degradation. Modifications in the siRNA may be in the nucleotide base, *i.e.*, the purine or the pyrimidine, the ribose or the phosphate. Preferably, the modification occurs at the 2' position of at least one ribose in an siRNA.

More specifically, the siRNA is modified in at least one pyrimidine, at least one purine or a combination thereof. However, generally all pyrimidines (cytosine or uracil), or all purines (adenosine or guanine) or a combination of all pyrimidines and all purines of the siRNA are modified. More preferably, the pyrimidines are modified, and these pyrimidines are cytosine, a derivative of cytosine, uracil, a derivative of uracil or a combination thereof. Ribonucleotides on either one or both strands of the siRNA may be modified.

Ribonucleotides containing pyrimidine bases found in RNA (cytidine and uridine) can be chemically modified by adding any molecule that inhibits RNA degradation or breakdown of the base, the ribose or the phosphates. As previously noted, the 2' position of ribose is a preferred site for modification. 2' modified siRNAs have a longer serum half-life and are resistant to degradation, relative to unmodified siRNAs or single-stranded RNAs, such as antisense or ribozyme. 2'-modified pyrimidine ribonucleotides can be formed by a number of different methods known in the art.

A preferable chemical modification is the addition of a molecule from the halide chemical group to a ribonucleotide of siRNA. Within the halides, fluorine is a preferred molecule. Besides fluoro-, other chemical moieties such as methyl-, methoxyethyl- and propyl- may be added as modifications. The most preferred

modification, though, is fluoro-modification, such as a 2'-fluoro-modification or a 2',2'-fluoro-modification.

Thus, in a preferred embodiment of the invention, siRNA is modified by the addition of a fluorine molecule to the 2' carbon of a pyrimidine ribonucleotide. The siRNA may be fluorinated completely or partially. For example, only the cytosine ribonucleotides may be fluorinated. Alternatively, only the uracil ribonucleotides may be fluorinated. In a preferred embodiment, both uracil and cytosine are fluorinated. Only one strand, either sense or antisense, of siRNA may to be fluorinated. Even partial 2' fluorination of siRNA gives protection against nucleolytic degradation. Importantly, 2' fluorinated siRNA is not toxic to cells, an unexpected result given that fluorine chemistry usually is toxic to living organisms.

In addition, modified siRNAs of the present invention may contain chemical modifications that inhibit viral RNA polymerases. For example, siRNAs may comprise one or more nucleosides that inhibit viral RNA-dependent RNA polymerases. Examples of such nucleosides and other chemical modifications exist in WO 02/057425, WO 02/057287, WO 02/18404, WO 02/100415, WO 02/32920, WO 01/90121, US patent No. 6,063,628 and US published application No. 2002/0019363.

siRNA can be prepared in a number of ways, such as by chemical synthesis, T7 polymerase transcription, or by treating long double stranded RNA (dsRNA) prepared by one of the two previous methods with Dicer enzyme. Dicer enzyme creates mixed populations of dsRNA from about 21 to about 23 base pairs in length from dsRNA that is about 500 base pairs to about 1000 base pairs in size. Unexpectedly, Dicer can effectively cleave modified strands of dsRNA, such as 2' fluoro-modified dsRNA. Before development of this method, it was previously thought that Dicer would not be able to cleave modified siRNA. The Dicer method of preparing siRNAs can be performed using a Dicer siRNA Generation Kit available from Gene Therapy Systems (San Diego, CA).

The invention particularly includes a method of making a modified siRNA that targets a nucleic acid sequence in a virus, comprising (a) preparing a modified-double stranded RNA (dsRNA) fragment containing at least one modified

ribonucleotide in at least one strand, and (b) cleaving the modified-dsRNA fragments with recombinant human Dicer, resulting in more than one modified siRNA. The method may further comprise (c) isolating the modified siRNAs.

In the methods for making siRNA, a dsRNA fragment can be prepared by chemical synthesis or in vitro translation. In one embodiment, the modified siRNA is a 2' modified siRNA in which the modification is at the 2' position of at least one ribonucleotide of said siRNA. The modification is selected from the group consisting of fluoro-, methyl-, methoxyethyl and propyl-modification. Preferably the fluoro-modification is a 2'-fluoro-modification or a 2',2'-fluoro-modification. The pyrimidines, the purines or a combination thereof of the siRNA are modified. More preferably, the pyrimidines are modified, such as cytosine, a derivative of cytosine, uracil, a derivative of uracil or a combination thereof. One or both strands of the siRNA may contain one or more modified ribonucleotide.

The invention further provides a method of inactivating a target agent or virus in a patient by administering to the patient a dsRNA in an effective amount to inactivate the targeted agent or virus. Preferably the dsRNA is modified as described above. RNA interference toward a targeted DNA segment in a cell can be achieved by administering a double-stranded RNA molecule to the cells, wherein the ribonucleotide sequence of the double-stranded RNA molecule corresponds to the ribonucleotide sequence of the targeted DNA segment. Preferably, the dsRNA used to induce targeted RNAi is siRNA.

As used herein "targeted DNA segment" is used to mean a DNA sequence encoding, in whole or in part, an mRNA for a targeted protein, including introns or exons, where suppression is desired. DNA segment can also mean a DNA sequence that normally regulates expression of the targeted protein, including but not limited to the promoter of the targeted protein. Furthermore, the DNA segment may or may not be a part of the cell's genome or it may be extrachromosomal, such as plasmid DNA.

The present invention is particularly directed to a method of inactivating a virus in a patient by administering to the patient an siRNA, preferably a modified siRNA, in an effective amount to inactivate the virus. The siRNA is preferably about

10 to about 30 ribonucleotides in length, more preferably 12-28 ribonucleotides, more preferably 15-25 ribonucleotides, even more preferably 19 –23 ribonucleotides and most preferably 21-23 ribonucleotides.

Also, the method of inactivating a virus preferably utilizes an siRNA that is modified at the 2' position of at least one ribonucleotide of said siRNA. The siRNA may be modified with chemical groups selected from the group consisting of fluoro-, methyl-, methoxyethyl- and propyl-. Fluoro-modification is most preferred, and either a 2'-fluoro-modification or a 2',2'-fluoro-modification is useful in the method. The modification may be at a pyrimidine, a purine or a combination thereof of the siRNA. More preferably the pyrimidines are modified, such as cytosine, a derivative of cytosine, uracil, a derivative of uracil or a combination thereof. In one embodiment, one strand of the siRNA contains at least one modified ribonucleotide, while in another embodiment, both strands of the siRNA contain at least one modified ribonucleotide.

siRNAs useful in treatment methods may also be modified by the attachment of at least one, but preferably more than one, receptor-binding ligand(s) to the siRNA. Such ligands are useful to direct delivery of siRNA to a target virus in a body system, organ, tissue or cells of a patient, such as the liver, gastrointestinal tract, respiratory tract, the cervix or the skin.

In preferred embodiments, receptor-binding ligands are attached to either a 5'-end or a 3'-end of an siRNA molecule. Receptor-binding ligands may be attached to one or more siRNA ends, including any combination of 5'- and 3'-ends. Thus, when receptor binding ligands are attached only to the ends of an siRNA molecule, anywhere between 1 and 4 such ligands may be attached.

The selection of an appropriate ligand for targeting siRNAs to viruses in particular body systems, organs, tissues or cells is considered to be within the ordinary skill of the art. For example, to target an siRNA to hepatocytes, cholesterol may be attached at one or more ends, including any combination of 5'- and 3'-ends, of an siRNA molecule. The resultant cholesterol-siRNA is delivered to hepatocytes in the liver, thereby providing a means to deliver siRNAs to this targeted location. Other

ligands useful for targeting siRNAs to the liver include HBV surface antigen and low-density lipoprotein (LDL).

As another example, siRNA molecules that target Human Immunodeficiency virus type 1 (HIV-1) can be delivered to T lymphocytes where the target nucleic acids are located (Song, E. *et al.*, *J. of Virology*, 77(13): 7174-7181 (2003)). This delivery can be accomplished by attaching, at the 3' -end or 5' -end of siRNA molecules, HIV-1 surface antigen capable of binding to the CD4 surface protein located on T-cells (Kilby, M. *et al.*, *New England J. of Medicine*, 348(22): 2228-38 (2003)).

Similarly, siRNA molecules that target Influenza A virus can be delivered to epithelial cells of the respiratory tract where the target nucleic acids are located (Ge, Q. *et al.*, *Proc. Natl. Acad. of Sciences*, 100(5): 2718-2723 (2002)). This delivery can be accomplished by attaching, at the 3' -end or 5' -end of siRNA molecules, the Influenza virus surface antigen, which is capable of binding to the sialic acid residues located on the surface of the epithelial cells (Ohuchi, M., *et al.*, *J. of Virology*, 76(24): 12405-12413 (2002); Glick, G. *et al.*, *J. of Biol. Chem.*, 266 (35): 23660-23669 (1991)).

Also, siRNA molecules that target respiratory syncitial virus (RSV) can be delivered to epithelial cells of the respiratory tract where the target nucleic acids are located (Bitko, V. *et al.*, *BMC Microbiology*, 1:34 (2001)). This delivery can be accomplished by attaching, at the 3' -end or 5' -end of siRNA molecules, RSV surface antigen (Malhotra, R. *et al.*, *Microbes and Infection*, 5: 123-133 (2003)).

As still another example, siRNAs that target Human Papillomavirus (HPV) can be delivered to basal epithelial cells where the target nucleic acids are located (Hall, A. *et al.*, *J. of Virology*, 77(10): 6066-6069 (2003)). This delivery can be accomplished by attaching, at the 3' -end or 5' -end of siRNA molecules, HPV surface antigen capable of binding to heparin sulfate proteoglycans located on the surface of basal epithelial cells (Bousarghin L. *et al.*, *J. of Virology*, 77(6): 3846-3850 (2002)).

Further, siRNAs that target Poliovirus (PV) can be delivered to cells of the nervous system where the target nucleic acids are located (Gitlin, L. *et al.*, *Nature*,

418: 430-434 (2002)). This delivery can be accomplished by attaching, at the 3' -end or 5' -end of siRNA molecules, PV surface antigen capable of binding to the CD155 receptor located on the surface of neurons (He, Y. *et al., Proc. Natl. Acad. of Sciences*, 97 (1): 79-84 (2000)).

As noted, the methods of treatment are intended to target disease-causing agents or pathogens, and more particularly viruses, which can be either RNA viruses or DNA viruses. Preferred viruses are selected from the group consisting of hepatitis C virus (HCV), hepatitis A virus, hepatitis B virus, hepatitis D virus, hepatitis E virus, Ebola virus, influenza virus, rotavirus, reovirus, retrovirus, poliovirus, human papilloma virus (HPV), metapneumovirus and coronavirus. More preferably the target virus is hepatitis C virus or a coronavirus.

In one aspect, the method utilizes an siRNA prepared by (a) identifying a target ribonucleotide sequence in a virus genome for designing a small interfering RNA (siRNA) and (b) producing a siRNA that has been modified to contain at least one modified ribonucleotide. Preferably, the siRNA comprises a double-stranded RNA molecule with a first strand ribonucleotide sequence corresponding to a ribonucleotide sequence corresponding to a target ribonucleotide sequence in the virus, and a second strand comprising a ribonucleotide sequence complementary to the target ribonucleotide sequence. The first and second strands should be separate complementary strands that hybridize to each other to form a double-stranded RNA molecule. Moreover, one or both of the strands should comprise at least one modified ribonucleotide.

In preferred embodiments of the invention, the siRNA targets a ribonucleotide sequence in the hepatitis C virus genome. The target ribonucleotide sequence comprises a conserved ribonucleotide sequence necessary for HCV replication, and the conserved ribonucleotide sequence is selected from the group consisting of 5'-untranslated region (5'-UTR), 3'-untranslated region (3'-UTR), core, and NS3 helicase. Highly preferred siRNA molecules comprise a sequence at least 80% identical to those of siRNA5, siRNAC1, siRNAC2, siRNA5B1, siRNA5B2, or siRNA5B4. The siRNAs may be unmodified, or modified as described above.

Methods of inhibiting the replication of HCV in cells positive for HCV should not be toxic to the cells, or cause apoptosis in the treated cells. Preferably, the inhibition of HCV replication is specifically tailored to affect only HCV replication in the cells, such that normal growth, division or metabolism is not affected. Cells in which HCV has been shown to replicate include, but are not limited to hepatic cells, B cell lymphocytes and T cell lymphocytes. Preferably, a method of inhibiting the replication of HCV is performed in hepatic cells.

According to the invention, "hepatic cells" can be from any animal source. Further, the hepatic cells may be in cell culture, or part of a tissue, or an organ, in part or in whole. The phrase hepatic cells is meant to include any cell constituting a normal, abnormal or diseased liver cell. Examples of hepatic cells include, but are not limited to, Kupffer cells, hepatocytes and cells comprising a hepatocellular carcinoma. "Hepatic cells" is not meant to include cells that make up discrete structures within the liver, such as endothelial cells lining blood vessels. A tissue or organ containing the hepatic cells may be within a subject or may be biopsied or removed from the animal. Additionally, the tissue may be "fresh" in that the tissue would be recently removed from a subject, without any preservation steps between the excision and the methods of the current invention. Prior to application of the methods of the current invention, the tissue may also have been preserved by such standard tissue preparation techniques including, but not limited to, freezing, quick freezing, paraffin embedding and tissue fixation. Furthermore, the tissue may also be a xenograft or a syngraft on or in another host animal. As used herein, the terms animal and subject are used interchangeably.

According to the invention, "hepatitis C virus," or "HCV," takes its ordinary meaning in the art as of the date of invention. The hepatitis C virus is an RNA virus of the *Flaviviridae* family. For example as used herein, HCV includes, but is not limited to genotypes 1-11 (using the most common genotyping system), with these genotypes being broken down into sub-types, some of which include but are not limited to 1a, 1b, 1c, 2a, 2b, 2c, 3a, 3b, 4a, 4b, 4c, 4d, 4e, 5a, 6a, 7a, 7b, 8a, 8b, 9a, 10a and 11a. Further, isolates from individuals consist of closely related yet heterogeneous populations of viral genomes, sometimes referred to as quasispecies.

Pestivirus is yet another target of the present invention. As used herein, "pestivirus" takes its ordinary meaning in the art as of the date of invention. The pestivirus belongs to the family *Flaviviridae*. Pestivirus is widespread throughout the Australian cattle population. It is believed that about 70% of herds are actively infected with pestivirus. Infection of susceptible animals can cause a variety of diseases - some not apparent until well after the initial spread of the virus into a herd. Pestivirus is a genus of viruses that includes hog cholera virus, bovine viral diarrhea virus (BVDV) and border disease virus (BDV) or hairy-shaker disease virus.

siRNA may be administered to a patient by intravenous injection, subcutaneous injection, oral delivery, liposome delivery or intranasal delivery. The siRNA may then accumulate in a target body system, organ, tissue or cell type of the patient.

The present invention also provides a method of inhibiting the replication of a virus in mammalian cells, comprising transfecting cells harboring the virus with a vector that directs the expression of virus-specific siRNA. In one embodiment, the invention provides a method of inhibiting the replication of hepatitis C virus (HCV) in cells positive for HCV, comprising transfecting HCV-positive cells with a vector that directs the expression of an HCV-specific siRNA. The cells may be evaluated to determine if a marker in the cells has been inhibited by the siRNA.

Thus, the invention also provides vectors and host cells comprising a nucleic acid segment encoding the described siRNAs.

Vectors of the present invention may be employed for producing siRNAs by recombinant techniques. Thus, for example, a DNA segment encoding an siRNA may be included in any one of a variety of expression vectors for expressing any DNA sequence. Such vectors include chromosomal, nonchromosomal and synthetic DNA sequences, e.g., derivatives of SV40; bacterial plasmids; phage DNA; baculovirus; yeast plasmids; vectors derived from combinations of plasmids and phage DNA, viral DNA such as vaccinia, adenovirus, fowl pox virus, and pseudorabies. However, any other vector may be used as long as it is replicable and viable in a desired host.

The appropriate DNA segment may be inserted into the vector by a variety of procedures. In general, the DNA sequence is inserted into an appropriate restriction endonuclease site(s) by procedures known in the art. Such procedures and others are deemed to be within the scope of those skilled in the art.

The DNA segment in the expression vector is operatively linked to an appropriate expression control sequence(s) (promoter) to direct siRNA synthesis. Suitable eukaryotic promoters include the CMV immediate early promoter, the HSV thymidine kinase promoter, the early and late SV40 promoters, the promoters of retroviral LTRs, such as those of the Rous Sarcoma Virus (RSV), and metallothionein promoters, such as the mouse metallothionein-I promoter. Preferably the promoters of the present invention are from the type III class of RNA polymerase III promoters. More preferably, the promoters are selected from the group consisting of the U6 and H1 promoters. The U6 and H1 promoters are both members of the type III class of RNA polymerase III promoters. The promoters of the present invention may also be inducible, in that expression may be turned "on" or "off." For example, a tetracycline-regulatable system employing the U6 promoter may be used to control the production of siRNA. The expression vector may or may not contain a ribosome binding site for translation initiation and a transcription terminator. The vector may also include appropriate sequences for amplifying expression.

In addition, the expression vectors preferably contain one or more selectable marker genes to provide a phenotypic trait for selection of transformed host cells such as dihydrofolate reductase or neomycin resistance for eukaryotic cell culture, or tetracycline or ampicillin resistance.

Generally, recombinant expression vectors will include origins of replication and selectable markers permitting transformation of the host cell, e.g., the ampicillin resistance gene of E. coli and S. cerevisiae TRP1 gene, and a promoter derived from a highly-expressed gene to direct transcription of a downstream structural sequence. Such promoters can be derived from operons encoding glycolytic enzymes such as 3-phosphoglycerate kinase (PGK), a-factor, acid phosphatase, or heat shock proteins, among others. The heterologous structural sequence is assembled in appropriate phase with translation initiation and termination sequences, and preferably, a leader

sequence capable of directing secretion of translated protein into the periplasmic space or extracellular medium. Optionally, the heterologous sequence can encode a fusion protein including an N-terminal identification peptide imparting desired characteristics, e.g., stabilization or simplified purification of expressed recombinant product.

In one embodiment, the invention provides a vector, wherein the DNA segment encoding the sense strand of the RNA polynucleotide is operably linked to a first promoter and where the DNA segment encoding the antisense (opposite) strand of the RNA polynucleotide molecule of is operably linked to a second promoter. In other words, each strand of the RNA polynucleotide is independently expressed. Furthermore, the promoter driving expression of each strand can be identical or each one may be different from the other promoter.

In another embodiment, the vector of the current invention may comprise opposing promoters. For example, the vector may comprise two U6 promoters on either side of the DNA segment encoding the sense strand of the RNA polynucleotide and placed in opposing orientations, with or without a transcription terminator placed between the two opposing promoters. The U6 opposing promoter construct is similar to the T7 opposing promoter construct as described in Wang, Z. *et al.*, J. Biol. Chem. 275: 40174-40179 (2000). See Miyagishi, M. and Taira, K., Nature Biotech. 20: 497-500 (2002).

In another embodiment, the DNA segments encoding both strands of the RNA polynucleotide are under the control of a single promoter. In one embodiment, the DNA segments encoding each strand are arranged on the vector with a "loop" region interspersed between the two DNA segments, where transcription f the DNA segments and loop region creates one RNA transcript. The single transcript will, in turn, anneal to itself creating a "hairpin" RNA structure capable of inducing RNAi. The "loop" of the hairpin structure is preferably from about 4 to about 6 nucleotides in length. More preferably, the loop is 4 nucleotides in length.

The vector containing the appropriate DNA sequence as described herein, as well as an appropriate promoter or control sequence, may be employed to transform

an appropriate host to permit the host to express the siRNA. Appropriate cloning and expression vectors for use with prokaryotic and eukaryotic hosts are described by Sambrook, et al., Molecular Cloning: A Laboratory Manual, Second Edition, Cold Spring Harbor, N.Y. (1989), the disclosure of which is hereby incorporated by reference.

Host cells are genetically engineered (transduced or transformed or transfected) with the vectors of this invention which may be, for example, cloning vectors or expression vectors. The vectors may be, for example, in the form of a plasmid, a viral particle, a phage, etc. The engineered host cells may be cultured in conventional nutrient media modified as appropriate for activating promoters, selecting transformants. The culture conditions, such as temperature, pH and the like, are those previously used with the host cell selected for expression, and will be apparent to the ordinarily skilled artisan.

In a further embodiment, the present invention relates to host cells containing the above-described constructs. A host cell may be a higher eukaryotic cell, such as a mammalian cell, or a lower eukaryotic cell, such as a yeast cell, or the host cell may be a prokaryotic cell, such as a bacterial cell. Preferably, host cells are mammalian cells. More preferably, host cells are hepatic cells. Introduction of a construct into host cells can be effected by calcium phosphate transfection, DEAE-Dextran mediated transfection, or electroporation (Davis, L., et al., Basic Methods in Molecular Biology (1986)).

The term patient, as used herein, refers to an animal, preferably a mammal. More preferably the patient can be a primate, including non-human and humans. The terms subject and patient are used interchangeably herein.

The treatments envisioned by the current invention can be used for subjects with a pre-existing viral infection, or for subjects pre-disposed to an infection. Additionally, the methods of the current invention can be used to correct or compensate for cellular or physiological abnormalities involved in conferring susceptibility to viral infections in patients, and/or to alleviate symptoms of a viral infections in patients, or as a preventative measure in patients.

The method of treating a patient having a viral infection involves administration of compositions to the subjects. As used herein, composition can mean a pure compound, agent or substance or a mixture of two or more compounds, agents or substances. As used herein, the term agent, substance or compound is intended to mean a protein, nucleic acid, carbohydrate, lipid, polymer or a small molecule, such as a drug.

In one embodiment of the current invention, the composition administered to the subject is a pharmaceutical composition. Further, the pharmaceutical composition can be administered orally, nasally, parenterally, intrasystemically, intraperitoneally, topically (as by drops or transdermal patch), bucally, or as an oral or nasal spray. Intranasal delivery of a virus that causes upper respiratory diseases, such as the coronavirus or the metapneumovirus, would be a particularly advantageous delivery mode. The term "parenteral," as used herein, refers to modes of administration that include intravenous, intramuscular, intraperitoneal, intrasternal, subcutaneous and intraarticular injection and infusion. The pharmaceutical compositions as contemplated by the current invention may also include a pharmaceutically acceptable carrier.

"Pharmaceutically acceptable carrier" includes, but is not limited to, a non-toxic solid, semisolid or liquid filler, diluent, encapsulating material or formulation auxiliary of any type, such as liposomes.

A pharmaceutical composition of the present invention for parenteral injection can comprise pharmaceutically acceptable sterile aqueous or nonaqueous solutions, dispersions, suspensions or emulsions as well as sterile powders for reconstitution into sterile injectable solutions or dispersions just prior to use. Examples of suitable aqueous and nonaqueous carriers, diluents, solvents or vehicles include water, ethanol, polyols (such as glycerol, propylene glycol, polyethylene glycol, and the like), carboxymethylcellulose and suitable mixtures thereof, vegetable oils (such as olive oil), and injectable organic esters such as ethyl oleate. Proper fluidity can be maintained, for example, by the use of coating materials such as lecithin, by the maintenance of the required particle size in the case of dispersions, and by the use of surfactants.

The compositions of the present invention can also contain adjuvants such as, but not limited to, preservatives, wetting agents, emulsifying agents, and dispersing agents. Prevention of the action of microorganisms can be ensured by the inclusion of various antibacterial and antifungal agents, for example, paraben, chlorobutanol, phenol, sorb acid, and the like. It can also be desirable to include isotonic agents such as sugars, sodium chloride, and the like. Prolonged absorption of the injectable pharmaceutical form can be brought about by the inclusion of agents which delay absorption such as aluminum monostearate and gelatin.

In some cases, to prolong the effect of the drugs, it is desirable to slow the absorption from subcutaneous or intramuscular injection. This can be accomplished by the use of a liquid suspension of crystalline or amorphous material with poor water solubility. The rate of absorption of the drug then depends upon its rate of dissolution which, in turn, can depend upon crystal size and crystalline form. Alternatively, delayed absorption of a parenterally administered drug form is accomplished by dissolving or suspending the drug in an oil vehicle.

Injectable depot forms are made by forming microencapsule matrices of the drug in biodegradable polymers such as polylactide-polyglycolide. Depending upon the ratio of drug to polymer and the nature of the particular polymer employed, the rate of drug release can be controlled. Examples of other biodegradable polymers include poly(orthoesters) and poly(anhydrides). Depot injectable formulations are also prepared by entrapping the drug in liposomes or microemulsions which are compatible with body tissues.

The injectable formulations can be sterilized, for example, by filtration through a bacterial-retaining filter, or by incorporating sterilizing agents in the form of sterile solid compositions which can be dissolved or dispersed in sterile water or other sterile injectable medium just prior to use.

Solid dosage forms for oral administration include, but are not limited to, capsules, tablets, pills, powders, and granules. In such solid dosage forms, the active compounds are mixed with at least one item pharmaceutically acceptable excipient or carrier such as sodium citrate or dicalcium phosphate and/or a) fillers or extenders

such as starches, lactose, sucrose, glucose, mannitol, and silicic acid, b) binders such as, for example, carboxymethylcellulose, alginates, gelatin, polyvinylpyrrolidone, sucrose, and acacia, c) humectants such as glycerol, d) disintegrating agents such as agar-agar, calcium carbonate, potato or tapioca starch, alginic acid, certain silicates, and sodium carbonate, e) solution retarding agents such as paraffin, f) absorption accelerators such as quaternary ammonium compounds, g) wetting agents such as, for example, acetyl alcohol and glycerol monostearate, h) absorbents such as kaolin and bentonite clay, and i) lubricants such as talc, calcium stearate, magnesium stearate, solid polyethylene glycols, sodium lauryl sulfate, and mixtures thereof. In the case of capsules, tablets and pills, the dosage form can also comprise buffering agents.

Solid compositions of a similar type can also be employed as fillers in soft and hard filled gelatin capsules using such excipients as lactose or milk sugar as well as high molecular weight polyethylene glycols and the like.

The solid dosage forms of tablets, dragees, capsules, pills, and granules can be prepared with coatings and shells such as enteric coatings and other coatings well known in the pharmaceutical formulating art. They can optionally contain opacifying agents and can also be of a composition that they release the active ingredient(s) only, or preferentially, in a certain part of the intestinal tract, optionally, in a delayed manner. Examples of embedding compositions which can be used include polymeric substances and waxes.

The active compounds can also be in micro-encapsulated form, if appropriate, with one or more of the above-mentioned excipients.

Liquid dosage forms for oral administration include, but are not limited to, pharmaceutically acceptable emulsions, solutions, suspensions, syrups and elixirs. In addition to the active compounds, the liquid dosage forms can contain inert diluents commonly used in the art such as, for example, water or other solvents, solubilizing agents and emulsifiers such as ethyl alcohol, isopropyl alcohol, ethyl carbonate, ethyl acetate, benzyl alcohol, benzyl benzoate, propylene glycol, 1,3-butylene glycol, dimethyl formamide, oils (in particular, cottonseed, groundnut, corn, germ, olive,

castor, and sesame oils), glycerol, tetrahydrofurfuryl alcohol, polyethylene glycols and fatty acid esters of sorbitan, and mixtures thereof.

Besides inert diluents, the oral compositions can also include adjuvants such as wetting agents, emulsifying and suspending agents, sweetening, flavoring, and perfuming agents.

Suspensions, in addition to the active compounds, can contain suspending agents as, for example, ethoxylated isostearyl alcohols, polyoxyethylene sorbitol and sorbitan esters, microcrystalline cellulose, aluminum metahydroxide, bentonite, agar-agar, and tragacanth, and mixtures thereof.

Alternatively, the composition can be pressurized and contain a compressed gas, such as nitrogen or a liquefied gas propellant. The liquefied propellant medium and indeed the total composition is preferably such that the active ingredients do not dissolve therein to any substantial extent. The pressurized composition can also contain a surface active agent. The surface active agent can be a liquid or solid non-ionic surface active agent or can be a solid anionic surface active agent. It is preferred to use the solid anionic surface active agent in the form of a sodium salt.

The compositions of the present invention can also be administered in the form of liposomes. As is known in the art, liposomes are generally derived from phospholipids or other lipid substances. Liposomes are formed by mono- or multi-lamellar hydrated liquid crystals that are dispersed in an aqueous medium. Any non-toxic, physiologically acceptable and metabolizable lipid capable of forming liposomes can be used. The present compositions in liposome form can contain, in addition to the compounds of the invention, stabilizers, preservatives, excipients, and the like. The preferred lipids are the phospholipids and the phosphatidyl cholines (lecithins), both natural and synthetic. Methods to form liposomes are known in the art (*see*, for example, Prescott, Ed., *Meth. Cell Biol. 14*:33 *et seq* (1976)).

One of ordinary skill in the art will appreciate that effective amounts of the agents of the invention can be determined empirically and can be employed in pure form or, where such forms exist, in pharmaceutically acceptable salt, ester or prodrug form. A "therapeutically effective" amount of the inventive compositions can be

determined by prevention or amelioration of adverse conditions or symptoms of diseases, injuries or disorders being treated. The agents can be administered to a subject, in need of treatment of viral infection, as pharmaceutical compositions in combination with one or more pharmaceutically acceptable excipients. It will be understood that, when administered to a human patient, the total daily usage of the agents or composition of the present invention will be decided by the attending physician within the scope of sound medical judgement. The specific therapeutically effective dose level for any particular patient will depend upon a variety of factors: the type and degree of the cellular or physiological response to be achieved; activity of the specific agent or composition employed; the specific agents or composition employed; the age, body weight, general health, sex and diet of the patient; the time of administration, route of administration, and rate of excretion of the agent; the duration of the treatment; drugs used in combination or coincidental with the specific agent; and like factors well known in the medical arts. For example, it is well within the skill of the art to start doses of the agents at levels lower than those required to achieve the desired therapeutic effect and to gradually increase the dosages until the desired effect is achieved.

Dosing also can be arranged in a patient specific manner to provide a predetermined concentration of the agents in the blood, as determined by techniques accepted and routine in the art. Thus patient dosaging can be adjusted to achieve regular on-going blood levels, as measured by HPLC, on the order of from 50 to 1000 ng/ml.

It will be readily apparent to one of ordinary skill in the relevant arts that other suitable modifications and adaptations to the methods and applications described herein can be made without departing from the scope of the invention or any embodiment thereof.

EXAMPLES

The examples demonstrate that siRNA, including modified siRNA, can effectively inhibit viral replication in mammalian cells. Moreover, the examples

show that the inventive siRNAs promote HCV RNA degradation in human liver cells and establish that hepatocytes possess the necessary functional components of modified siRNA-induced silencing. The examples also demonstrate that siRNA technology can be used as a therapy to inhibit HCV replication in host cells. The inventors, by submitting the following examples, do not intend to limit the scope of the claimed invention.

EXAMPLE 1

To test whether siRNA directed to the HCV genome confers intracellular immunity against this human pathogen, a recently developed HCV cell culture systems in human hepatoma cell line, Huh-7, was used. One of the cell lines, 5-2, harbors autonomously replicating subgenomic HCV RNA (Bartenschlager, J. Virol, 2001). The subgenomic replicon carries firefly luciferase gene, allowing a reporter function assay as a measure of HCV RNA replication (Fig. 5). Owing to cell culture adaptive mutations introduced into the genome (Bart), these 5-2 cells replicate HCV RNA at levels of up to 5×10^4 virus particles/cell.

Using T7 transcription, several 21-bp siRNA duplexes against different regions of the 5'-UTR of the HCV genome were made (Fig 5). Briefly, 2 oligo double-stranded DNA molecules comprising the T7 promoter and the 5' UTR of HCV being oriented in either the sense direction or the antisense direction were generated. Each oligo DNA was then transcribed *in vitro* to produce (+) and (-) RNA and then treated with DNAase I to remove the DNA template. The two RNA strands were allowed to anneal at 37°C overnight, generating dsRNA. After treating the dsRNA with RNAase T1 to remove unreacted ssRNA species, the dsRNA was purified for transfection.

Several other siRNA duplexes were designed, including GL2 and GL3, that were directed against the fruit fly and sea pansy luciferase genes, respectively. Using standard transfection techniques, the siRNAs were transfected into the 5-2 cells and luciferase activity was measured to determine the effect of the siRNAs on HCV replication. Luciferase activity was measured 48 hours after transfection. In cells

where siRNA5 was transfected, there was reduced luciferase activity of up to 85%, in a dose responsive manner (Fig. 6). The inhibition of luciferase activity was not seen in cells that were transfected with irrelevant siRNA (SIN). The sequence of SIN was taken from sindbis virus transcription promoter (Fig. 1).

EXAMPLE 2

The sequence specificity of the siRNA5 response was further tested using additional siRNA duplexes, GL2 and GL3. Figure 1 shows that GL2 and GL3 differ from each other by 3-nucleotides. Luciferase activity was reduced by 90% in cells transfected with siRNA5 or GL2, but no significant reduction was seen in cells transfected with GL3 (Fig. 7). The luciferase assay was performed using a Luciferase assay system available from Promega Corp. (Madison, WI), according to the manufacturer's instructions.

EXAMPLE 3

Whether or not siRNA5 was toxic to transfected cells also was tested. Toxicity was by measured using an ATPase activity assay. Figure 8 shows that the siRNA5-induced reduction in HCV replication, as seen in Figure 6, was not due to cellular toxicity which is attributed to non sequence-specific RNAi. ATPase levels were assayed using an ATPase assay kit from Promega (Madison, WI) according to the manufacturer's instructions.

EXAMPLE 4

The full-length HCV replicon may possess the ability to adapt and suppress RNAi, thus replicating in spite of the presence of siRNA, as documented in Li, H, Science 296:1319-1321 (2002). To determine the effects of siRNA5 on replication of full-length HCV RNA in Huh-7 cells, from the 21-5 cell line, harboring the selectable full-length HCV replicon, were treated with siRNA5. Levels of HCV RNA were measured by quantitative PCR using TaqMan™ (F. Hoffman La-Roche, Switzerland). The results as seen in Figure 9 show that siRNA-directed silencing reduced steady-

state viral RNA production, even in the setting of an adapted HCV mutant, where RNA replication was very high. Results from both subgenomic and full-length HCV replicons suggest that none of the HCV proteins can suppress RNA interference.

EXAMPLE 5

Whether or not siRNA5 was toxic to transfected cells also was tested. Specifically, mRNA encoding GAPDH, an enzyme essential in glycolysis, was measured in Huh 5-2 cells transfected with siRNA5, or siRNA specific towards the GAPDH sequence. Figure 10 demonstrates that siRNA5 did not affect RNA levels of GAPDH. GAPDH was measured using a TaqMan™ RNA kit (F. Hoffman La-Roche, Switzerland) according to the manufacturer's instructions.

EXAMPLE 6

To test the effectiveness of siRNA5 on inhibiting the ability of HCV to replicate in an infected liver, potions of HCV-infected human liver are xenografted onto transgenic severe combined immunodeficient (SCID) mice according to methods well known to the skilled artisan.

Briefly, once the HCV-infected liver has supplanted the mouse liver, liposome-encapsulated siRNA5, or control liposomes are administered by intravenous injection to the mice through the tail vein, or another accessible vein. The mice are dosed one time a day for 3-10 days.

At the end of the dosing regimen the mice are sacrificed and blood collected and the livers removed. The liver is divided into portions such that a portion is frozen using liquid nitrogen, a portion is fixed for paraffin embedding, and a portion is fixed for sectioning onto slides.

Using the appropriate allotment, HCV RNA is quantified using the TaqMan™ RNA assay kit previously utilized herein to determine the levels of HCV RNA in the liver cells. Further, anti-HCV antibody titers can be measured in the collected blood samples, along with serum ALT levels.

EXAMPLE 7

To test the effectiveness of siRNA5 on inhibiting the ability of HCV to infect a healthy liver, potions of normal human liver are xenografted onto transgenic severe combined immunodeficient (SCID) mice according to methods well known to the skilled artisan.

Briefly, once the healthy liver has supplanted the mouse liver, liposome-encapsulated siRNA5, or control liposomes are administered by intravenous injection to the mice through the tail vein, or another accessible vein. The mice are dosed one time a day for 3-10 days. After the pre-dosing regimen, active HCV is then injected intravenously, or via hepatic injection, into the mice.

At about 6, 12, 18, 24 hours, and periodically up to about 5 days after the mice are infected with HCV, the mice are sacrificed and blood collected and the livers removed. The liver is divided into portions such that a portion is frozen using liquid nitrogen, a portion is fixed for paraffin embedding, and a portion is fixed for sectioning onto slides.

Using the appropriate allotment, HCV RNA is quantified using the TaqMan™ RNA assay kit previously utilized herein to determine the levels of HCV RNA in the liver cells. Further, anti-HCV antibody titers can be measured in the collected blood samples, along with serum ALT levels.

EXAMPLE 8

Modified siRNA can be prepared by chemical synthesis. In one embodiment, each C and U within a siRNA duplex, *e.g.* GL2, can be substituted with 2'-F-U and 2'F-C. To produce siRNA with 3'-end overhangs comprising 2'-F-U and 2'F-C, a universal support can be used. By selectively cleaving the oligo from the support, a practitioner can ensure that residues of the overhangs comprise modified nucleotides. Alternatively, the nucleotides comprising the 3'-end overhang can be unmodified dTdT.

2'-F RNA oligonucleotides can be synthesized on an Applied Biosystems 8909 or 8905 DNA/RNA synthesizer using the standard 1μmol beta-cyanoethyl phosphoramidite RNA chemistry protocol. The RNA phosphoramidite monomers and columns of Pac-A, 2'-F-Ac-C, iPr-Pac-G, 2'-F-U, and U-RNA CPG can be obtained from Glen Research (Sterling, VA). (See catalog nos. 10-3000-05, 10-3415-02, 10-3021-05, 10-3430-02, and 20-3430-41E, respectively.) Glen Research's Sulfurizing Reagent (catalog no. 40-4036-10) can be used as an oxidant to obtain a single phosphorothioate backbone between the 3' CPG and a subsequent base. To attain the coupling, the oxidizing step of the standard RNA 1μmol protocol can be replaced with the standard thioate 1 μmol protocol. Cholesteryl-TEG phosphoramidite (Glen Research, catalog no. 10-1975-90) and cholestryl-TEG CPG (Glen Research, catalog no. 20-2975-41E) can be incorporated onto the 5' or 3' ends of one or more of the oliogoribonucleotides. After synthesis, the 2'-F RNA's are cleaved and deprotected with 1:1 ammonium hydroxide/methylamine, and the silyl groups are removed with triethylamine trihydrofluoride using standard protocols. *See e.g.* http://www.glenres.com/productfiles/technical/tb_rnadeprotection.pdf. The oligoribonucleotides are then desalted on Sephadex G25 columns (Pharmacia NAP 25, catalog no. 17-08252-02) with sterilized water and purified using standard gel electrophoresis protocols. Modified siRNAs also can be obtained from commercial vendors such as Dharmacon (Lafayette, CO).

Alternatively, modified siRNA can be prepared by transcription using the Durascribe™ T7 Transcription Kit purchased from Epicentre Technologies (Madison, WI).

The modified siRNAs (dsRNAs) made by these methods contain phosphodiester linked oligonucleotides. Standard methods for making modified single-stranded RNAs, such as antisense molecules, are useful for making modified siRNAs, as modified single-stranded RNAs can be annealed together to form double stranded RNAs. Such standard methods include, but are not limited to, those described in Chiang *et al.*, *J.Biol.Chem.* 266, 18162-18171 (1991); Baker *et al.*, *J.Biol.Chem.* 272, 11994-12000 (1997); Kawasaki *et al.*, *J.Med.Chem.* 36, 831-841 (1993); Monia *et al.*, *J.Biol.Chem.* 268, 14514-14522 (1993).

EXAMPLE 9

To test whether siRNA directed to the HCV genome confers intracellular immunity against this human pathogen, a recently developed HCV cell culture systems in human hepatoma cell line, Huh-7, was used. One of the cell lines, 5-2, harbors autonomously replicating subgenomic HCV RNA (Bartenschlager, J. Virol, 2001). The subgenomic replicon carries firefly luciferase gene, allowing a reporter function assay as a measure of HCV RNA replication. Owing to cell culture adaptive mutations introduced into the genome, 5-2 cells replicate HCV RNA at levels of up to 5×10^4 virus particles/cell.

Using T7 transcription, several 21-bp siRNA duplexes against different regions of the 5'-UTR of the HCV genome were made. Briefly, two oligo double-stranded DNA molecules comprising the T7 promoter and the 5' UTR of HCV being oriented in either the sense direction or the antisense direction were generated. Each oligo DNA was then transcribed *in vitro* to produce (+) and (-) RNA and then treated with DNAase I to remove the DNA template. The two RNA strands were allowed to anneal at 37°C overnight, generating dsRNA. After treating the dsRNA with RNAase T1 to remove the unreacted ssRNA species, the dsRNA was purified for transfection.

Two exemplary modified siRNAs are provided below:

Chol-GL2	Chol-CGUACGCGGAAUACUUCGAUU UUGCAUGCGCCUUAUGAAGCU
GL2	CGUACGCGGAAUACUUCGAUU UUGCAUGCGCCUUAUGAAGCU

Each C and U within siRNA GL2, directed against the fruit fly luciferase gene, was substituted with 2'-F-U and 2'F-C. The modified siRNAs were transfected into the 5-2 cells using standard liposome transfection techniques. Specifically, the modified siRNAs were incubated for 4 hrs at 37°C in a 250 µl cell suspension containing 0.5 µl of Oligofectamine (Invitrogen, Carlsbad, CA), for 20 hrs in 375 µl serum containing culture medium, and for 24 hrs at 37°C in fresh medium without the

liposome-siRNA complex. Luciferase activity was measured 48 hours after transfection to determine the effect of the modified siRNAs on HCV replication.

Figure 11 shows that GL2 reduced the luciferase activity at increasing concentrations. Luciferase activity was reduced by 90% in cells transfected with 2'-F-GL2, but no significant reduction was seen in mocked transfected cells or with a control (2'-F-GFP=green fluorescent protein). The luciferase assay was carried out using a Luciferase assay system available from Promega Corp. (Madison, WI), according to the manufacturer's instructions.

The siRNA Chol-GL2 comprises a cholesteryl group on one of the 5' ends. 5-2 cells were incubated with various concentrations of Chol-GL2 in the absence of liposomes. Cells were harvested 48 hours after incubation and assayed for luciferase activity. Figure 12 shows that Chol-GL2 inhibited luciferase gene activity in a dose-dependent manner. InvA refers to chol-GL2 in inverted sequence.

EXAMPLE 10

To test the stability of 2' chemically modified siRNA compared to unmodified siRNA (siRNA), the following experiment is performed. Four nanograms of siRNA are added to a 20 μL volume of 80% human serum from a healthy donor. This mixture is incubated at 37 C° for various times ranging from 1 minute up to 10 days. The results are depicted in lanes 2-10 of Figure 13. The same process is performed for 2' fluorine modified siRNA (2'-F siRNA) as well and the results are shown in lanes 12-20 and 22-25 of Figure 3. When the incubation process is finished, the mixtures are placed on ice and then immediately separated by PAGE along with a ^{32}P-siRNA control (See Lanes 1, 11 and 21 of Figure 13). The data show that the 2'-modified siRNA is stable over a period of 10 days as compared to unmodified siRNA.

EXAMPLE 11

To demonstrate the production of modified siRNA from long dsRNA, five micrograms of 1000 bp-long fluorinated dsRNAs (Figure 14, panel (A)) were incubated overnight with 15 units of human Dicer at 37°C. The resulting diced-

siRNAs were purified using a Sephadex G-25 column and electrophoresed on 20% PAGE (Figure 14, panel (B)). Figure 4 shows that recombinant human dicer effectively converts fluorinated-dsRNA into 2'F-siRNA.

EXAMPLE 12

To further test whether siRNAs directed to the HCV genome confer intracellular immunity against this human pathogen, the assay described in Example 1 was employed to test siRNAC1, siRNAC2, siRNA5B1, siRNA5B2, and siRNA5B4, each of which is shown in Figure 2. Each siRNA was tested at concentrations of 1 nM, 10nM and 100 nM. As shown in Figure 15, each of the siRNAs significantly inhibited luciferase activity in a dose-dependent manner. SiRNAC2 exhibited particular effectiveness.

EXAMPLE 13

As a follow-up to the experiments reported in Example 9, assays were performed to demonstrate that the cholesterol modification, and not the fluoro modification directed siRNA molecules to Huh-7 liver cells. Huh-7 cells were incubated with various concentrations of two kinds of Chol-GL2 siRNAs: one having a 2'-fluoro modification and the other lacking such a modification. The results, shown in Figure 16 demonstrate that the deliver of cholesterol-modified siRNA molecules to liver cells is due to the cholesterol, and not other modifications.

WHAT IS CLAIMED IS:

1. A method for inactivating a virus in a patient, comprising administering to said patient a modified siRNA in an effective amount to inactivate said virus.

2. The method of claim 1, wherein said modified siRNA is a 2' modified siRNA.

3. The method of claim 2, wherein the modification is at the 2' position of at least one ribonucleotide of said siRNA.

4. The method of claim 1, 2 or 3, wherein said modification is selected from the group consisting of fluoro-, methyl-, methoxyethyl- and propyl-modification.

5. The method of claim 4, wherein said fluoro-modification is a 2'-fluoro-modification or a 2',2'-fluoro-modification.

6. The method of any one of claims 1-5, wherein pyrimidines of said siRNA are modified, and said pyrimidines are cytosine, a derivative of cytosine, uracil, a derivative of uracil or a combination thereof.

7. The method of any one of claims 1-6, wherein both strands of said siRNA contain at least one modified nucleotide.

8. The method of any one of claims 1-7, wherein said virus is selected from the group consisting of hepatitis C virus (HCV), hepatitis A virus, hepatitis B virus, hepatitis D virus, hepatitis E virus, Ebola virus, influenza virus, rotavirus, reovirus, retrovirus, poliovirus, human papilloma virus (HPV), metapneumovirus and coronavirus.

9. The method of any one of claims 1-8, wherein said virus is hepatitis C virus.

10. The method of any one of claims 1-9, wherein said siRNA is prepared by

(a) identifying a target nucleotide sequence in an HCV genome for designing a small interfering RNA (siRNA); and

(b) producing an siRNA that has been modified to contain at least one modified nucleotide.

11. The method of any one of claims 1-9, wherein said siRNA is prepared by

(a) identifying a target nucleotide sequence in a virus genome for designing a small interfering RNA (siRNA); and

(b) producing an siRNA that has been modified to contain at least one modified nucleotide.

12. The method of claim 10, wherein said target nucleotide sequence is selected from the group consisting of 5'-untranslated region (5'-UTR), 3'-untranslated region (3'-UTR), core, and NS3 helicase.

13. The method of any one of claims 1-12, wherein said siRNA is siRNA5, siRNAC1, siRNAC2, siRNA5B1, siRNA5B2 or siRNA5B4.

14. An siRNA comprising a modified ribonucleotide, wherein said siRNA is resistant to RNase and retains the ability to inhibit viral replication.

15. The siRNA of claim 14, wherein said modified siRNA is a 2' modified siRNA.

16. The siRNA of claim 15, wherein the modification is at the 2' position of at least one ribonucleotide of said siRNA.

17. The siRNA of any one of claims 14-16, wherein the modification is selected from the group consisting of fluoro-, methyl-, methoxyethyl- and propyl-modification.

18. The siRNA of claim 17, wherein said fluoro-modification is a 2'-fluoro-medication or a 2',2'-fluoro-modification.

19. The method of any one of claims 14-18, wherein pyrimidines of said siRNA are modified, and said pyrimidines are cytosine, a derivative of cytosine, uracil, a derivative of uracil or a combination thereof.

20. The siRNA of any one of claims 14-19, wherein both strands of the siRNA contains modified nucleotides.

21. The siRNA of any one of claims 14-20, wherein said siRNA interacts with a target nucleotide sequence in a virus genome.

22. The siRNA of claim 21, wherein said virus is selected from the group consisting of hepatitis C virus (HCV), hepatitis A virus, hepatitis B virus, hepatitis D virus, hepatitis E virus, Ebola virus, influenza virus, rotavirus, reovirus, retrovirus, poliovirus, human papilloma virus (HPV), metapneumovirus and coronavirus.

23. The siRNA of claim 22, wherein said virus is hepatitis C virus (HCV).

24. A method of making a modified siRNA that targets a nucleic acid sequence in a virus comprising:

(a) preparing a modified-double stranded RNA (dsRNA) fragment containing at least one modified ribonucleotide in at least one strand that spans the genome of a target agent; and

(b) cleaving said modified-dsRNA fragments with recombinant human Dicer resulting in more than one modified siRNA.

25. The method of claim 24, further comprising:
(c) isolating said modified siRNAs.

26. The method of claim 24 or 25, wherein said target agent is a virus.

27. The method of claim 26, wherein said virus is selected from the group consisting of hepatitis C virus (HCV), hepatitis A virus, hepatitis B virus, hepatitis D virus, hepatitis E virus, Ebola virus, influenza virus, rotavirus, reovirus, retrovirus, poliovirus, human papilloma virus (HPV), metapneumovirus and coronavirus.

28. A method for inactivating a virus in a patient comprising administering to said patient a modified siRNA consisting of about 10 to about 30 ribonucleotides in an effective amount to inactivate said virus.

29. The method of claim 28, wherein said modified siRNA consists of about 19 to about 23 ribonucleotides.

30. The method of claim 28 or 29, wherein said modified siRNA is a 2' modified siRNA.

31. The method of any one of claims 28-30, wherein the modification is at the 2' position of at least one ribonucleotide of said siRNA.

32. The method of any one of claims 28-31, wherein said modification is selected from the group consisting of fluoro-, methyl-, methoxyethyl- and propyl-modification.

33. The method of claim 32, wherein said fluoro-modification is a 2'-fluoro-modification or a 2',2'-fluoro-modification.

34. The method of any one of claims 28-33, wherein pyrimidines of said siRNA are modified and said pyrimidines are cytosine, a derivative of cytosine, uracil, a derivative of uracil or a combination thereof.

35. The method of any one of claims 28-34, wherein both strands of said siRNA contain modified nucleotides.

36. The method of any one of claims 28-35, wherein said virus is selected from the group consisting of hepatitis C virus (HCV), hepatitis A virus, hepatitis B virus, hepatitis D virus, hepatitis E virus, Ebola virus, influenza virus, rotavirus, reovirus, retrovirus, poliovirus, human papilloma virus (HPV), metapneumovirus and coronavirus.

37. The method of any one of claims 28-36, wherein said virus is hepatitis C virus (HCV).

38. The method of any one of claims 28-37, wherein said siRNA is prepared by

(a) identifying a target nucleotide sequence in a HCV genome for designing a small interfering RNA (siRNA); and

(b) producing an siRNA that has been modified to contain at least one modified nucleotide.

39. The method of any one of claims 28-37, wherein said siRNA is prepared by

(a) identifying a target nucleotide sequence in a virus genome for designing a small interfering RNA (siRNA); and

(b) producing an siRNA that has been modified to contain at least one modified nucleotide.

40. The method of claim 38, wherein said target nucleotide sequence comprises a conserved nucleotide sequence necessary for HCV replication.

41. The method of claim 40, wherein said conserved nucleotide sequence is selected from the group consisting of 5'-untranslated region (5'-UTR), 3'-untranslated region (3'-UTR), core, and NS3 helicase.

42. The method of any one of claims 28-41, wherein said siRNA is siRNA5, siRNAC1, siRNAC2, siRNA5B1, siRNA5B2 or siRNA5B4.

43. A double-stranded RNA molecule of from about 10 to about 30 nucleotides that inhibits replication of hepatitis C virus (HCV).

44. The double-stranded RNA molecule of claim 43 comprising a nucleotide sequence at least 80% identical to the nucleotide sequence of siRNA5, siRNAC1, siRNAC2, siRNA5B1, siRNA5B2 or siRNA5B4.

45. A method of inducing targeted RNA interference toward HCV in hepatic cells, comprising administering the double-stranded RNA molecule of claim 43 or 44 to hepatic cells, wherein the nucleotide sequence of said double-stranded RNA molecule corresponds to an HCV nucleotide sequence.

46. A method of inhibiting replication of hepatitis C virus (HCV), comprising administering the RNA polynucleotide molecule of claim 43 or 44 to cells infected with HCV.

47. A vector comprising a DNA segment encoding the RNA molecule of claim 43 or 44.

48. The vector of claim 47, wherein the sense strand of said double-stranded RNA molecule is operably linked to a first promoter and wherein the antisense strand of said double-stranded RNA molecule of is operably linked to a second promoter.

49. The vector of claim 48, wherein said first and second promoters are selected from the group consisting of U6 and H1.

50. The vector of claim 48 or 49 wherein said first and second promoters are the same.

51. The vector of claim 47, wherein the sense and antisense strands of said RNA molecule are under the control of a single promoter.

52. The vector of claim 51, wherein said single promoter is selected from the group consisting of U6 and H1.

53. A host cell comprising the vector of any one of claims 47-52.

54. A method of inhibiting replication of hepatitis C virus (HCV) in cells carrying HCV, comprising transfecting said cells with the vector of any one of claims 47-52.

55. A method of treating hepatitis C in a subject in need thereof, comprising administering a composition comprising the RNA molecule of claim 43 or 44 to said subject.

56. A method of treating hepatitis C in a subject in need thereof, comprising administering the vector of any one of claims 47-52 to said subject.

57. A modified siRNA molecule, comprising a double-stranded RNA molecule of from about 10 to about 30 nucleotides in length, which mediates RNA interference toward a target agent or virus, and which is linked to at least one receptor-binding ligand.

58. The modified siRNA molecule of claim 57, wherein said receptor-binding ligand is attached to a 5' -end or 3' -end of said siRNA molecule.

59. The modified siRNA molecule of claim 57 or 58, wherein said receptor binding ligand is attached to multiple ends of said siRNA molecule.

60. The modified siRNA molecule of any one of claims 57-59, wherein said receptor-binding ligand is selected from the group consisting of a cholesterol, an HBV surface antigen, low-density lipoprotein, an HIV-1 surface antigen, an influenza virus surface antigen, an RSV surface antigen, an HPV surface antigen and a polio virus surface antigen.

61. The modified siRNA molecule of any one of claims 57-60, wherein said receptor-binding ligand is cholesterol.

62. The modified siRNA molecule of any one of claims 57-61, further comprising a modification at the 2' position of at least one ribonucleotide, which modification at the 2' position of at least one ribonucleotide renders said siRNA resistant to degradation.

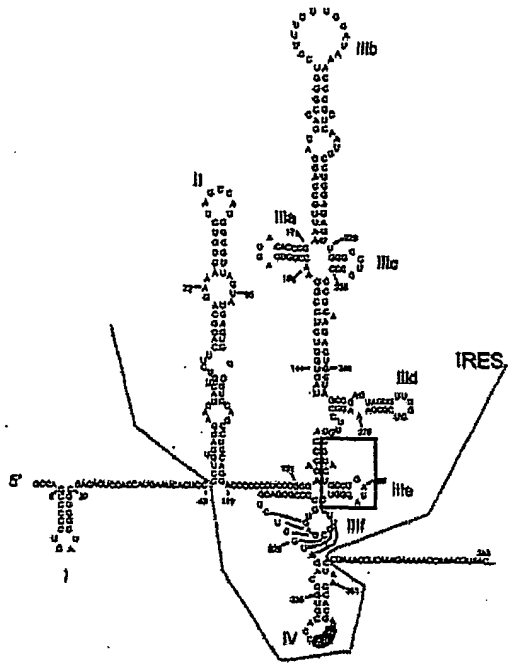
63. The modified siRNA molecule of claim 62, wherein said modification at the 2' position of at least one ribonucleotide is a 2'-fluoro-modification or a 2',2'-fluoro-modification.

64. A method of inducing targeted RNA interference in a patient, comprising administering to said patient an effective amount of the siRNA of any one of claims 57-63.

65. A method of inducing targeted RNA interference in a patient, comprising administering to said patient an effective amount of the siRNA of claim 61.

66. A method of inducing targeted RNA interference in a patient, comprising administering to said patient an effective amount of the siRNA of claim 63.

Fig. 1. The Sequence and Secondary Structure of 5'UTR of HCV Genome.



The region where siRNAs was designed is boxed.
The sequence of the 21-bp $siRNA_5$ is shown below.

	286 304
$siRNA_5$	5'-GUACUGCCUGAUAGGGUGCUU UUCAUGACGGACUAUCCCACG-5'
GL2	5'-CGUACGCGGAAUACUUCGAUU UUGCAUGCGCCUUAUGAAGCU-5'
GL3	5'-CUUACGCUGAGUACUUCGAUU UUGAAUGCGACUCAUGAAGCU--5'
SIN	5'-AUCUCUACGGUGGUCCUAAUU UUUAGAGAUGCCACCAGGAUU--5'

Fig. 2

	Domain	sequence (NN-N19-NN)	Position		
5U8	5'UTR	cc-CUGUGAGGAACUACUGUCU-uc	45-63	sense	CUGUGAGGAACUACUGUCUUC
				antisense	AGACAGUAGUUCCUCACAGGG
5U9		ua-CUGUCUUCACGCAGAAAGC-gu	58-76	sense	CUGUCUUCACGCAGAAAGCGU
				antisense	GCUUUCUGCGUGAAGACAGUA
5U10		cg-AGACUGCUAGCCGAGUAGU-gu	244-262	sense	AGACUGCUAGCCGAGUAGUGU
				antisense	ACUACUCGGCUAGCAGUCUCG
C1	Core	ga-AUCCUAAACCUCAAAGAAA-aa	352-370	sense	AUCCUAAACCUCAAAGAAAAA
				antisense	UUUCUUUGAGGUUUAGGAUUC
C2		gg-UCAGAUCGUCGGUGGAGUU-ua	425-443	sense	UCAGAUCGUCGGUGGAGUUUA
				antisense	AACUCCACCGACGAUCUGACC
C3		gg-UAAGGUCAUCGAUACCCUC-ac	701-719	sense	UAAGGUCAUCGAUACCCUCAC
				antisense	GAGGGUAUCGAUGACCUUACC
C4		ac-GGCGUGAACUAUGCAACAG-gg	822-840	sense	GGCGUGAACUAUGCAACAGGG
				antisense	CUGUUGCAUAGUUCACGCCGU
C5		cc-GGUUGCUCCUUUUCUAUCU-uc	852-870	sense	GGUUGCUCCUUUUCUAUCUUC
				antisense	AGAUAGAAAAGGAGCAACCGG
5B1	NS5B	gc-UCUUCAUACGGAUUCCAAU-ac	8163-8181	sense	UCUUCAUACGGAUUCCAAUAC
				antisense	AUUGGAAUCCGUAUGAAGAGC
5B2		ca-UACGGAUUCCAAUACUCUC-cu	8167-8187	sense	UACGGAUUCCAAUACUCUCCU
				antisense	GAGAGUAUUGGAAUCCGUAUG
5B3		uu-UGACUCAACGGUCACUGAG-aa	8270-8288	sense	UGACUCAACGGUCACUGAGAA
				antisense	CUCAGUGACCGUUGAGUCAAA
5B4		cc-UUCACGGAGGCUAUGACUA-ga	8613-8631	sense	UUCACGGAGGCUAUGACUAGA
				antisense	UAGUCAUAGCCUCCGUGAAGG
5B5		au-ACGACUUGGAGUUGAUAAC-au	8671-8689	sense	ACGACUUGGAGUUGAUAACAU
				antisense	GUUAUCAACUCCAAGUCGUAU
5B6		au-UCCUGGCUAGGCAACAUCA-uc	8817-8835	sense	UCCUGGCUAGGCAACAUCAUC
				antisense	UGAUGUUGCCUAGCCAGGAAU
5B7		uu-GUGGCAAGUACCUCUUCAA-cu	9160-9178	sense	GUGGCAAGUACCUCUUCAACU
				antisense	UUGAAGAGGUACUUGCCACAA
5B8		au-GUGGUGCCUACUCCUACUU-uc	9317-9335	sense	GUGGUGCCUACUCCUACUUUC
				antisense	AAGUAGGAGUAGGCACCACAU
3U1	3'UTR	cu-UUGGUGGCUCCAUCUUAGC-cc	9506-9524	sense	UUGGUGGCUCCAUCUUAGCCC
				antisense	GCUAAGAUGGAGCCACCAAAG
3U2		gu-CACGGCUAGCUGUGAAAGG-uc	9531-9549	sense	CACGGCUAGCUGUGAAAGGUC
				antisense	CCUUUCACAGCUAGCCGUGAC
3U3		ag-CCGCUUGACUGCAGAGAGU-gc	9558-9576	sense	CCGCUUGACUGCAGAGAGUGC
				antisense	ACUCUCUGCAGUCAAGCGGCU

Fig. 3

1 ttattaggtt tttacctacc caggaaaagc caaccaacct cgatctcttg tagatctgtt
61 ctctaaacga actttaaaat ctgtgtagct gtcgctcggc tgcatgccta gtgcacctac
121 gcagtataaa caataataaa ttttactgtc gttgacaaga aacgagtaac tcgtccctct
181 tctgcagact gcttacggtt tcgtccgtgt tgcagtcgat catcagcata cctaggtttc
241 gtccgggtgt gaccgaaagg taagatggag agccttgttc ttggtgtcaa cgagaaaaca
301 cacgtccaac tcagtttgcc tgtccttcag gttagagacg tgctagtgcg tggcttcggg
361 gactctgtgg aagaggccct atcggaggca cgtgaacacc tcaaaaatgg cacttgtggt
421 ctagtagagc tggaaaaagg cgtactgccc cagcttgaac agccctatgt gttcattaaa
481 cgttctgatg ccttaagcac caatcacggc cacaaggtcg ttgagctggt tgcagaaatg
541 gacggcattc agtacggtcg tagcggtata acactgggag tactcgtgcc acatgtgggc
601 gaaaccccaa ttgcataccg caatgttctt cttcgtaaga acggtaataa gggagccggt
661 ggtcatagct atggcatcga tctaaagtct tatgacttag gtgacgagct tggcactgat
721 cccattgaag attatgaaca aaactggaac actaagcatg gcagtggtgc actccgtgaa
781 ctcactcgtg agctcaatgg aggtgcagtc actcgctatg tcgacaacaa tttctgtggc
841 ccagatgggt accctcttga ttgcatcaaa gattttctcg cacgcgcggg caagtcaatg
901 tgcactcttt ccgaacaact tgattacatc gagtcgaaga gaggtgtcta ctgctgccgt
961 gaccatgagc atgaaattgc ctggttcact gagcgctctg ataagagcta cgagcaccag
1021 acacccttcg aaattaagag tgccaagaaa tttgacactt tcaaagggga atgcccaaag
1081 tttgtgtttc ctcttaactc aaaagtcaaa gtcattcaac cacgtgttga aaagaaaaag
1141 actgagggtt tcatggggcg tatacgctct gtgtaccctg ttgcatctcc acaggagtgt
1201 aacaatatgc acttgtctac cttgatgaaa tgtaatcatt gcgatgaagt ttcatggcag
1261 acgtgcgact ttctgaaagc cacttgtgaa cattgtggca ctgaaaattt agttattgaa
1321 ggacctacta catgtgggta cctacctact aatgctgtag tgaaaatgcc atgtcctgcc
1381 tgtcaagacc cagagattgg acctgagcat agtgttgcag attatcacaa ccactcaaac
1441 attgaaactc gactccgcaa gggaggtagg actagatgtt ttggaggctg tgtgtttgcc
1501 tatgttggct gctataataa gcgtgcctac tgggttcctc gtgctagtgc tgatattggc
1561 tcaggccata ctggcattac tggtgacaat gtggagacct tgaatgagga tctccttgag
1621 atactgagtc gtgaacgtgt taacattaac attgttggcg attttcattt gaatgaagag
1681 gttgccatca ttttggcatc tttctctgct tctacaagtg cctttattga cactataaag
1741 agtcttgatt acaagtcttt caaaaccatt gttgagtcct gcggtaacta taaagttacc
1801 aagggaaagc ccgtaaaagg tgcttggaac attggacaac agagatcagt tttaacacca
1861 ctgtgtggtt ttccctcaca ggctgctggt gttatcagat caatttttgc gcgcacactt
1921 gatgcagcaa accactcaat tcctgatttg caaagagcag ctgtcaccat acttgatggt
1981 atttctgaac agtcattacg tcttgtcgac gccatggttt atacttcaga cctgctcacc
2041 aacagtgtca ttattatggc atatgtaact ggtggtcttg tacaacagac ttctcagtgg
2101 ttgtctaatc ttttgggcac tactgttgaa aaactcaggc ctatctttga atggattgag
2161 gcgaaactta gtgcaggagt tgaatttctc aaggatgctt gggagattct caaatttctc
2221 attacaggtg tttttgacat cgtcaagggt caaatacagg ttgcttcaga taacatcaag
2281 gattgtgtaa aatgcttcat tgatgttgtt aacaaggcac tcgaaatgtg cattgatcaa
2341 gtcactatcg ctggcgcaaa gttgcgatca ctcaacttag gtgaagtctt catcgctcaa
2401 agcaagggac tttaccgtca gtgtatacgt ggcaaggagc agctgcaact actcatgcct
2461 cttaaggcac caaaagaagt aacctttctt gaaggtgatt cacatgacac agtacttacc
2521 tctgaggagg ttgttctcaa gaacggtgaa ctcgaagcac tcgagacgcc cgttgatagc
2581 ttcacaaatg gagctatcgt cggcacacca gtctgtgtaa atggcctcat gctcttagag
2641 attaaggaca aagaacaata ctgcgcattg tctcctggtt tactggctac aaacaatgtc
2701 tttcgcttaa aaggggtgc accaattaaa ggtgtaacct ttggagaaga tactgtttgg
2761 gaagttcaag gttacaagaa tgtgagaatc acatttgagc ttgatgaacg tgttgacaaa

2821 gtgcttaatg aaaagtgctc tgtctacact gttgaatccg gtaccgaagt tactgagttt
2881 gcatgtgttg tagcagaggc tgttgtgaag actttacaac cagtttctga tctccttacc
2941 aacatgggta ttgatcttga tgagtggagt gtagctacat tctacttatt tgatgatgct
3001 ggtgaagaaa acttttcatc acgtatgtat tgttcctttt accctccaga tgaggaagaa
3061 gaggacgatg cagagtgtga ggaagaagaa attgatgaaa cctgtgaaca tgagtacggt
3121 acagaggatg attatcaagg tctccctctg gaatttggtg cctcagctga aacagttcga
3181 gttgaggaag aagaagagga agactggctg gatgatacta ctgagcaatc agagattgag
3241 ccagaaccag aacctacacc tgaagaacca gttaatcagt ttactggtta tttaaaactt
3301 actgacaatg ttgccattaa atgtgttgac atcgttaagg aggcacaaag tgctaatcct
3361 atggtgattg taaatgctgc taacatacac ctgaaacatg gtggtggtgt agcaggtgca
3421 ctcaacaagg caaccaatgg tgccatgcaa aaggagagtg atgattacat taagctaaat
3481 ggccctctta cagtaggagg gtcttgtttg ctttctggac ataatcttgc taagaagtgt
3541 ctgcatgttg ttggacctaa cctaaatgca ggtgaggaca tccagcttct taaggcagca
3601 tatgaaaatt tcaattcaca ggacatctta cttgcaccat tgttgtcagc aggcatattt
3661 ggtgctaaac cacttcagtc tttacaagtg tgcgtgcaga cggttcgtac acaggtttat
3721 attgcagtca atgacaaagc tctttatgag caggttgtca tggattatct tgataacctg
3781 aagcctagag tggaagcacc taaacaagag gagccaccaa acacagaaga ttccaaaact
3841 gaggagaaat ctgtcgtaca gaagcctgtc gatgtgaagc caaaaattaa ggcctgcatt
3901 gatgaggtta ccacaacact ggaagaaact aagtttctta ccaataagtt actcttgttt
3961 gctgatatca atggtaagct ttaccatgat tctcagaaca tgcttagagg tgaagatatg
4021 tctttccttg agaaggatgc accttacatg gtaggtgatg ttatcactag tggtgatatc
4081 acttgtgttg taataccctc caaaaaggct ggtggcacta ctgagatgct ctcaagagct
4141 ttgaagaaag tgccagttga tgagtatata accacgtacc ctggacaagg atgtgctggt
4201 tatacacttg aggaagctaa gactgctctt aagaaatgca aatctgcatt ttatgtacta
4261 ccttcagaag cacctaatgc taaggaagag attctaggaa ctgtatcctg gaatttgaga
4321 gaaatgcttg ctcatgctga agagacaaga aaattaatgc ctatatgcat ggatgttaga
4381 gccataatgg caaccatcca acgtaagtat aaaggaatta aaattcaaga gggcatcgtt
4441 gactatggtg tccgattctt cttttatact agtaaagagc ctgtagcttc tattattacg
4501 aagctgaact ctctaaatga gccgcttgtc acaatgccaa ttggttatgt gacacatggt
4561 tttaatcttg aagaggctgc gcgctgtatg cgttctctta aagctcctgc cgtagtgtca
4621 gtatcatcac cagatgctgt tactacatat aatggatacc tcacttcgtc atcaaagaca
4681 tctgaggagc actttgtaga aacagtttct ttggctggct cttacagaga ttggtcctat
4741 tcaggacagc gtacagagtt aggtgttgaa tttcttaagc gtggtgacaa aattgtgtac
4801 cacactctgg agagccccgt cgagtttcat cttgacggtg aggttctttc acttgacaaa
4861 ctaaagagtc tcttatccct gcgggaggtt aagactataa aagtgttcac aactgtggac
4921 aacactaatc tccacacaca gcttgtggat atgtctatga catatggaca gcagtttggt
4981 ccaacatact tggatggtgc tgatgttaca aaaattaaac ctcatgtaaa tcatgagggt
5041 aagactttct ttgtactacc tagtgatgac acactacgta gtgaagcttt cgagtactac
5101 catactcttg atgagagttt tcttggtagg tacatgtctg ctttaaacca cacaaagaaa
5161 tggaaatttc ctcaagttgg tggtttaact tcaattaaat gggctgataa caattgttat
5221 ttgtctagtg ttttattagc acttcaacag cttgaagtca aattcaatgc accagcactt
5281 caagaggctt attatagagc ccgtgctggt gatgctgcta acttttgtgc actcatactc
5341 gcttacagta ataaaactgt tggcgagctt ggtgatgtca gagaaactat gacccatctt
5401 ctacagcatg ctaatttgga atctgcaaag cgagttctta atgtggtgtg taaacattgt
5461 ggtcagaaaa ctactacctt aacgggtgta gaagctgtga tgtatatggg tactctatct
5521 tatgataatc ttaagacagg tgtttccatt ccatgtgtgt gtggtcgtga tgctacacaa
5581 tatctagtac aacaagagtc ttcttttgtt atgatgtctg caccacctgc tgagtataaa
5641 ttacagcaag gtacattctt atgtgcgaat gagtacactg gtaactatca gtgtggtcat
5701 tacactcata taactgctaa ggagaccctc tatcgtattg acggagctca ccttacaaag
5761 atgtcagagt acaaaggacc agtgactgat gttttctaca aggaaacatc ttacactaca
5821 accatcaagc ctgtgtcgta taaactcgat ggagttactt acacagagat tgaaccaaaa
5881 ttggatgggt attataaaaa ggataatgct tactatacag agcagcctat agaccttgta
5941 ccaactcaac cattaccaaa tgcgagtttt gataatttca aactcacatg ttctaacaca
6001 aaatttgctg atgatttaaa tcaaatgaca ggcttcacaa agccagcttc acgagagcta
6061 tctgtcacat tcttcccaga cttgaatggc gatgtagtgg ctattgacta tagacactat
6121 tcagcgagtt tcaagaaagg tgctaaatta ctgcataagc caattgtttg gcacattaac

6181 caggctacaa ccaagacaac gttcaaacca aacacttggt gtttacgttg tctttggagt
6241 acaaagccag tagatacttc aaattcattt gaagttctgg cagtagaaga cacacaagga
6301 atggacaatc ttgcttgtga aagtcaacaa cccacctctg aagaagtagt ggaaaatcct
6361 accatacaga aggaagtcat agagtgtgac gtgaaaacta ccgaagttgt aggcaatgtc
6421 atacttaaac catcagatga aggtgttaaa gtaacacaag agttaggtca tgaggatctt
6481 atggctgctt atgtggaaaa cacaagcatt accattaaga aacctaatga gctttcacta
6541 gccttaggtt taaaaacaat tgccactcat ggtattgctg caattaatag tgttccttgg
6601 agtaaaattt tggcttatgt caaaccattc ttaggacaag cagcaattac aacatcaaat
6661 tgcgctaaga gattagcaca acgtgtgttt aacaattata tgccttatgt gtttacatta
6721 ttgttccaat tgtgtacttt tactaaaagt accaattcta gaattagagc ttcactacct
6781 acaactattg ctaaaaatag tgttaagagt gttgctaaat tatgtttgga tgccggcatt
6841 aattatgtga agtcacccaa attttctaaa ttgttcacaa tcgctatgtg gctattgttg
6901 ttaagtattt gcttaggttc tctaatctgt gtaactgctg cttttggtgt actcttatct
6961 aatttttggtg ctccttctta ttgtaatggc gttagagaat tgtatcttaa ttcgtctaac
7021 gttactacta tggatttctg tgaaggttct tttccttgca gcatttgttt aagtggatta
7081 gactcccttg attcttatcc agctcttgaa accattcagg tgacgatttc atcgtacaag
7141 ctagacttga caattttagg tctggccgct gagtgggttt tggcatatat gttgttcaca
7201 aaattctttt atttattagg tctttcagct ataatgcagg tgttctttgg ctattttgct
7261 agtcatttca tcagcaattc ttggctcatg tggtttatca ttagtattgt acaaatggca
7321 cccgtttctg caatggttag gatgtacatc ttctttgctt ctttctacta catatggaag
7381 agctatgttc atatcatgga tggttgcacc tcttcgactt gcatgatgtg ctataagcgc
7441 aatcgtgcca cacgcgttga gtgtacaact attgttaatg gcatgaagag atctttctat
7501 gtctatgcaa atggaggccg tggcttctgc aagactcaca attggaattg tctcaattgt
7561 gacacatttt gcactggtag tacattcatt agtgatgaag ttgctcgtga tttgtcactc
7621 cagtttaaaa gaccaatcaa ccctactgac cagtcatcgt atattgttga tagtgttgct
7681 gtgaaaaatg gcgcgcttca cctctacttt gacaaggctg gtcaaaagac ctatgagaga
7741 catccgctct cccattttgt caatttagac aatttgagag ctaacaacac taaaggttca
7801 ctgcctatta atgtcatagt ttttgatggc aagtccaaat gcgacgagtc tgcttctaag
7861 tctgcttctg tgtactacag tcagctgatg tgccaaccta ttctgttgct tgaccaagct
7921 cttgtatcag acgttggaga tagtactgaa gtttccgtta agatgtttga tgcttatgtc
7981 gacacctttt cagcaacttt tagtgttcct atggaaaaac ttaaggcact tgttgctaca
8041 gctcacagcg agttagcaaa gggtgtagct ttagatggtg tcctttctac attcgtgtca
8101 gctgcccgac aaggtgttgt tgataccgat gttgacacaa aggatgttat tgaatgtctc
8161 aaactttcac atcactctga cttagaagtg acaggtgaca gttgtaacaa tttcatgctc
8221 acctataata aggttgaaaa catgacgccc agagatcttg gcgcatgtat tgactgtaat
8281 gcaaggcata tcaatgccca agtagcaaaa agtcacaatg tttcactcat ctggaatgta
8341 aaagactaca tgtctttatc tgaacagctg cgtaaacaaa ttcgtagtgc tgccaagaag
8401 aacaacatac cttttagact aacttgtgct acaactagac aggttgtcaa tgtcataact
8461 actaaaatct cactcaaggg tggtaagatt gttagtactt gttttaaact tatgcttaag
8521 gccacattat tgtgcgttct tgctgcattg gtttgttata tcgttatgcc agtacataca
8581 ttgtcaatcc atgatggtta cacaaatgaa atcattggtt acaaagccat tcaggatggt
8641 gtcactcgtg acatcatttc tactgatgat tgttttgcaa ataaacatgc tggttttgac
8701 gcatggttta gccagcgtgg tggttcatac aaaaatgaca aaagctgccc tgtagtagct
8761 gctatcatta caagagagat tggtttcata gtgcctggct taccgggtac tgtgctgaga
8821 gcaatcaatg gtgacttctt gcattttcta cctcgtgttt ttagtgctgt tggcaacatt
8881 tgctacacac cttccaaact cattgagtat agtgattttg ctacctctgc ttgcgttctt
8941 gctgctgagt gtacaatttt taaggatgct atgggcaaac ctgtgccata ttgttatgac
9001 actaatttgc tagagggttc tatttcttat agtgagcttc gtccagacac tcgttatgtg
9061 cttatggatg gttccatcat acagtttcct aacacttacc tggagggttc tgttagagta
9121 gtaacaactt ttgatgctga gtactgtaga catggtacat gcgaaaggtc agaagtaggt
9181 atttgcctat ctaccagtgg tagatgggtt cttaataatg agcattacag agctctatca
9241 ggagttttct gtggtgttga tgcgatgaat ctcatagcta acatctttac tcctcttgtg
9301 caacctgtgg gtgctttaga tgtgtctgct tcagtagtgg ctggtggtat tattgccata
9361 ttggtgactt gtgctgccta ctactttatg aaattcagac gtgtttttgg tgagtacaac
9421 catgttgttg ctgctaatgc actttgttt ttgatgtctt tcactatact ctgtctggta
9481 ccagcttaca gctttctgcc gggagtctac tcagtctttt acttgtactt gacattctat

9541 ttcaccaatg atgtttcatt cttggctcac cttcaatggt ttgccatgtt ttctcctatt
9601 gtgccttttt ggataacagc aatctatgta ttctgtattt ctctgaagca ctgccattgg
9661 ttctttaaca actatcttag gaaaagagtc atgtttaatg gagttacatt tagtaccttc
9721 gaggaggctg ctttgtgtac ctttttgctc aacaaggaaa tgtacctaaa attgcgtagc
9781 gagacactgt tgccacttac acagtataac aggtatcttg ctctatataa caagtacaag
9841 tatttcagtg gagccttaga tactaccagc tatcgtgaag cagcttgctg ccacttagca
9901 aaggctctaa atgactttag caactcaggt gctgatgttc tctaccaacc accacagaca
9961 tcaatcactt ctgctgttct gcagagtggt tttaggaaaa tggcattccc gtcaggcaaa
10021 gttgaagggt gcatggtaca agtaacctgt ggaactacaa ctcttaatgg attgtggttg
10081 gatgacacag tatactgtcc aagacatgtc atttgcacag cagaagacat gcttaatcct
10141 aactatgaag atctgctcat tcgcaaatcc aaccatagct ttcttgttca ggctggcaat
10201 gttcaacttc gtgttattgg ccattctatg caaaattgtc tgcttaggct taaagttgat
10261 acttctaacc ctaagacacc caagtataaa tttgtccgta tccaacctgg tcaaacattt
10321 tcagttctag catgctacaa tggttcacca tctggtgttt atcagtgtgc catgagacct
10381 aatcatacca ttaaaggttc tttccttaat ggatcatgtg gtagtgttgg ttttaacatt
10441 gattatgatt gcgtgtcttt ctgctatatg catcatatgg agcttccaac aggagtacac
10501 gctggtactg acttagaagg taaattctat ggtccatttg ttgacagaca aactgcacag
10561 gctgcaggta cagacacaac cataacatta aatgttttgg catggctgta tgctgctgtt
10621 atcaatggtg ataggtggtt tcttaataga ttcaccacta ctttgaatga ctttaacctt
10681 gtggcaatga agtacaacta tgaacctttg acacaagatc atgttgacat attgggacct
10741 ctttctgctc aaacaggaat tgccgtctta gatatgtgtg ctgctttgaa agagctgctg
10801 cagaatggta tgaatggtcg tactatcctt ggtagcacta ttttagaaga tgagtttaca
10861 ccatttgatg ttgttagaca atgctctggt gttaccttcc aaggtaagtt caagaaaatt
10921 gttaagggca ctcatcattg gatgctttta actttcttga catcactatt gattcttgtt
10981 caaagtacac agtggtcact gtttttcttt gtttacgaga atgctttctt gccatttact
11041 cttggtatta tggcaattgc tgcatgtgct atgctgcttg ttaagcataa gcacgcattc
11101 ttgtgcttgt ttctgttacc ttctcttgca acagttgctt actttaatat ggtctacatg
11161 cctgctagct gggtgatgcg tatcatgaca tggcttgaat tggctgacac tagcttgtct
11221 ggttataggc ttaaggattg tgttatgtat gcttcagctt tagttttgct tattctcatg
11281 acagctcgca ctgtttatga tgatgctgct agacgtgttt ggacactgat gaatgtcatt
11341 acacttgttt acaaagtcta ctatggtaat gctttagatc aagctatttc catgtgggcc
11401 ttagttattt ctgtaacctc taactattct ggtgtcgtta cgactatcat gtttttagct
11461 agagctatag tgtttgtgtg tgttgagtat tacccattgt tatttattac tggcaacacc
11521 ttacagtgta tcatgcttgt ttattgtttc ttaggctatt gttgctgctg ctactttggc
11581 cttttctgtt tactcaaccg ttacttcagg cttactcttg gtgtttatga ctacttggtc
11641 tctacacaag aatttaggta tatgaactcc caggggcttt tgcctcctaa gagtagtatt
11701 gatgctttca agcttaacat taagttgttg ggtattggag gtaaaccatg tatcaaggtt
11761 gctactgtac agtctaaaat gtctgacgta aagtgcacat ctgtggtact gctctcggtt
11821 cttcaacaac ttagagtaga gtcatcttct aaattgtggg cacaatgtgt acaactccac
11881 aatgatattc ttcttgcaaa agacacaact gaagctttcg agaagatggt ttctcttttg
11941 tctgttttgc tatccatgca gggtgctgta gacattaata ggttgtgcga ggaaatgctc
12001 gataaccgtg ctactcttca ggctattgct tcagaattta gttctttacc atcatatgcc
12061 gcttatgcca ctgcccagga ggcctatgag caggctgtag ctaatggtga ttctgaagtc
12121 gttctcaaaa agttaaagaa atctttgaat gtggctaaat ctgagtttga ccgtgatgct
12181 gccatgcaac gcaagttgga aaagatggca gatcaggcta tgacccaaat gtacaaacag
12241 gcaagatctg aggacaagag ggcaaaagta actagtgcta tgcaaacaat gctcttcact
12301 atgcttagga agcttgataa tgatgcactt aacaacatta tcaacaatgc gcgtgatggt
12361 tgtgttccac tcaacatcat accattgact acagcagcca aactcatggt tgttgtccct
12421 gattatggta cctacaagaa cacttgtgat ggtaacacct ttacatatgc atctgcactc
12481 tgggaaatcc agcaagttgt tgatgcggat agcaagattg ttcaacttag tgaaattaac
12541 atggacaatt caccaaattt ggcttggcct cttattgtta cagctctaag agccaactca
12601 gctgttaaac tacagaataa tgaactgagt ccagtagcac tacgacagat gtcctgtgcg
12661 gctggtacca cacaaacagc ttgtactgat gacaatgcac ttgcctacta taacaattcg
12721 aagggaggta ggtttgtgct ggcattacta tcagaccacc aagatctcaa atgggctaga
12781 ttccctaaga gtgatggtac aggtacaatt tacacagaac tggaaccacc ttgtaggttt
12841 gttacagaca caccaaaagg gcctaaagtg aaatacttgt acttcatcaa aggcttaaac

12901 aacctaaata gaggtatggt gctgggcagt ttagctgcta cagtacgtct tcaggctgga
12961 aatgctacag aagtacctgc caattcaact gtgctttcct tctgtgcttt tgcagtagac
13021 cctgctaaag catataagga ttacctagca agtggaggac aaccaatcac caactgtgtg
13081 aagatgttgt gtacacacac tggtacagga caggcaatta ctgtaacacc agaagctaac
13141 atggaccaag agtcctttgg tggtgcttca tgttgtctgt attgtagatg ccacattgac
13201 catccaaatc ctaaaggatt ctgtgacttg aaaggtaagt acgtccaaat acctaccact
13261 tgtgctaatg acccagtggg ttttacactt agaaacacag tctgtaccgt ctgcggaatg
13321 tggaaaggtt atggctgtag ttgtgaccaa ctccgcgaac ccttgatgca gtctgcggat
13381 gcatcaacgt ttttaaacgg gtttgcggtg taagtgcagc ccgtcttaca ccgtgcggca
13441 caggcactag tactgatgtc gtctacaggg cttttgatat ttacaacgaa aaagttgctg
13501 gttttgcaaa gttcctaaaa actaattgct gtcgcttcca ggagaaggat gaggaaggca
13561 atttattaga ctcttacttt gtagttaaga ggcatactat gtctaactac caacatgaag
13621 agactattta taacttggtt aaagattgtc cagcggttgc tgtccatgac tttttcaagt
13681 ttagagtaga tggtgacatg gtaccacata tatcacgtca gcgtctaact aaatacacaa
13741 tggctgattt agtctatgct ctacgtcatt ttgatgaggg taattgtgat acattaaaag
13801 aaatactcgt cacatacaat tgctgtgatg atgattattt caataagaag gattggtatg
13861 acttcgtaga gaatcctgac atcttacgcg tatatgctaa cttaggtgag cgtgtacgcc
13921 aatcattatt aaagactgta caattctgcg atgctatgcg tgatgcaggc attgtaggcg
13981 tactgacatt agataatcag gatcttaatg ggaactggta cgatttcggt gatttcgtac
14041 aagtagcacc aggctgcgga gttcctattg tggattcata ttactcattg ctgatgccca
14101 tcctcacttt gactagggca ttggctgctg agtcccatat ggatgctgat ctcgcaaaac
14161 cacttattaa gtgggatttg ctgaaatatg attttacgga agagagactt tgtctcttcg
14221 accgttattt taaatattgg gaccagacat accatcccaa ttgtattaac tgtttggatg
14281 ataggtgtat ccttcattgt gcaaacttta atgtgttatt ttctactgtg tttccaccta
14341 caagttttgg accactagta agaaaaatat ttgtagatgg tgttcctttt gttgtttcaa
14401 ctggatacca ttttcgtgag ttaggagtcg tacataatca ggatgtaaac ttacatagct
14461 cgcgtctcag tttcaaggaa cttttagtgt atgctgctga tccagctatg catgcagctt
14521 ctggcaattt attgctagat aaacgcacta catgcttttc agtagctgca ctaacaaaca
14581 atgttgcttt tcaaactgtc aaacccggta attttaataa agacttttat gactttgctg
14641 tgtctaaagg tttctttaag gaaggaagtt ctgttgaact aaaacacttc ttctttgctc
14701 aggatggcaa cgctgctatc agtgattatg actattatcg ttataatctg ccaacaatgt
14761 gtgatatcag acaactccta ttcgtagttg aagttgttga taaatacttt gattgttacg
14821 atggtggctg tattaatgcc aaccaagtaa tcgttaacaa tctggataaa tcagctggtt
14881 tcccatttaa taaatggggt aaggctagac tttattatga ctcaatgagt tatgaggatc
14941 aagatgcact tttcgcgtat actaagcgta atgtcatccc tactataact caaatgaatc
15001 ttaagtatgc cattagtgca aagaatagag ctcgcaccgt agctggtgtc tctatctgta
15061 gtactatgac aaatagacag tttcatcaga aattattgaa gtcaatagcc gccactagag
15121 gagctactgt ggtaattgga acaagcaagt tttacggtgg ctggcataat atgttaaaaa
15181 ctgtttacag tgatgtagaa actccacacc ttatgggttg ggattatcca aaatgtgaca
15241 gagccatgcc taacatgctt aggataatgg cctctcttgt tcttgctcgc aaacataaca
15301 cttgctgtaa cttatcacac cgtttctaca ggttagctaa cgagtgtgcg caagtattaa
15361 gtgagatggt catgtgtggc ggctcactat atgttaaacc aggtggaaca tcatccggtg
15421 atgctacaac tgcttatgct aatagtgtct ttaacatttg tcaagctgtt acagccaatg
15481 taaatgcact tctttcaact gatggtaata agatagctga caagtatgtc cgcaatctac
15541 aacacaggct ctatgagtgt ctctatagaa atagggatgt tgatcatgaa ttcgtggatg
15601 agttttacgc ttacctgcgt aaacatttct ccatgatgat tctttctgat gatgccgttg
15661 tgtgctataa cagtaactat gcggctcaag gtttagtagc tagcattaag aactttaagg
15721 cagttcttta ttatcaaaat aatgtgttca tgtctgaggc aaaatgttgg actgagactg
15781 accttactaa aggacctcac gaattttgct cacagcatac aatgctagtt aaacaaggag
15841 atgattacgt gtacctgcct tacccagatc catcaagaat attaggcgca ggctgttttg
15901 tcgatgatat tgtcaaaaca gatggtacac ttatgattga aaggttcgtg tcactggcta
15961 ttgatgctta cccacttaca aaacatccta atcaggagta tgctgatgtc tttcacttgt
16021 atttacaata cattagaaag ttacatgatg agcttactgg ccacatgttg gacatgtatt
16081 ccgtaatgct aactaatgat aacacctcac ggtactggga acctgagttt tatgaggcta
16141 tgtacacacc acatacagtc ttgcaggctg taggtgcttg tgtattgtgc aattcacaga
16201 cttcacttcg ttgcggtgcc tgtattagga gaccattcct atgttgcaag tgctgctatg

16261 accatgtcat ttcaacatca cacaaattag tgttgtctgt taatccctat gtttgcaatg
16321 ccccaggttg tgatgtcact gatgtgacac aactgtatct aggaggtatg agctattatt
16381 gcaagtcaca taagcctccc attagtttc cattatgtgc taatggtcag gtttttggtt
16441 tatacaaaaa cacatgtgta ggcagtgaca atgtcactga cttcaatgcg atagcaacat
16501 gtgattggac taatgctggc gattacatac ttgccaacac ttgtactgag agactcaagc
16561 ttttcgcagc agaaacgctc aaagccactg aggaaacatt taagctgtca tatggtattg
16621 ccactgtacg cgaagtactc tctgacagag aattgcatct ttcatgggag gttggaaaac
16681 ctagaccacc attgaacaga aactatgtct ttactggtta ccgtgtaact aaaaatagta
16741 aagtacagat tggagagtac acctttgaaa aaggtgacta tggtgatgct gttgtgtaca
16801 gaggtactac gacatacaag ttgaatgttg gtgattactt tgtgttgaca tctcacactg
16861 taatgccact tagtgcacct actctagtgc cacaagagca ctatgtgaga attactggct
16921 tgtacccaac actcaacatc tcagatgagt tttctagcaa tgttgcaaat tatcaaaagg
16981 tcggcatgca aaagtactct acactccaag gaccacctgg tactggtaag agtcattttg
17041 ccatcggact tgctctctat tacccatctg ctcgcatagt gtatacggca tgctctcatg
17101 cagctgttga tgccctatgt gaaaaggcat taaaatattt gcccatagat aaatgtagta
17161 gaatcatacc tgcgcgtgcg cgcgtagagt gttttgataa attcaaagtg aattcaacac
17221 tagaacagta tgttttctgc actgtaaatg cattgccaga aacaactgct gacattgtag
17281 tctttgatga aatctctatg gctactaatt atgacttgag tgttgtcaat gctagacttc
17341 gtgcaaaaca ctacgtctat attggcgatc ctgctcaatt accagccccc cgcacattgc
17401 tgactaaagg cacactagaa ccagaatatt ttaattcagt gtgcagactt atgaaaacaa
17461 taggtccaga catgttcctt ggaacttgtc gccgttgtcc tgctgaaatt gttgacactg
17521 tgagtgcttt agtttatgac aataagctaa aagcacacaa ggataagtca gctcaatgct
17581 tcaaaatgtt ctacaaaggt gttattacac atgatgtttc atctgcaatc aacagacctc
17641 aaataggcgt tgtaagagaa tttcttacac gcaatcctgc ttggagaaaa gctgttttta
17701 tctcacctta taattcacag aacgctgtag cttcaaaaat cttaggattg cctacgcaga
17761 ctgttgattc atcacagggt tctgaatatg actatgtcat attcacacaa actactgaaa
17821 cagcacactc ttgtaatgtc aaccgcttca atgtggctat cacaagggca aaaattggca
17881 ttttgtgcat aatgtctgat agagatcttt atgacaaact gcaatttaca agtctagaaa
17941 taccacgtcg caatgtggct acattacaag cagaaaatgt aactggactt tttaaggact
18001 gtagtaagat cattactggt cttcatccta cacaggcacc tacacacctc agcgttgata
18061 taaagttcaa gactgaagga ttatgtgttg acataccagg cataccaaag gacatgacct
18121 accgtagact catctctatg atgggtttca aaatgaatta ccaagtcaat ggttacccta
18181 atatgtttat cacccgcgaa gaagctattc gtcacgttcg tgcgtggatt ggctttgatg
18241 tagagggctg tcatgcaact agagatgctg tgggtactaa cctacctctc cagctaggat
18301 tttctacagg tgttaactta gtagctgtac cgactggtta tgttgacact gaaaataaca
18361 cagaattcac cagagttaat gcaaaacctc caccaggtga ccagtttaaa catcttatac
18421 cactcatgta taaaggcttg ccctggaatg tagtgcgtat taagatagta caaatgctca
18481 gtgatacact gaaaggattg tcagacagag tcgtgttcgt cctttgggcg catggctttg
18541 agcttacatc aatgaagtac tttgtcaaga ttggacctga aagaacgtgt tgtctgtgtg
18601 acaaacgtgc aacttgcttt tctacttcat cagatactta tgcctgctgg aatcattctg
18661 tgggttttga ctatgtctat aacccattta tgattgatgt tcagcagtgg ggctttacgg
18721 gtaaccttca gagtaaccat gaccaacatt gccaggtaca tggaaatgca catgtggcta
18781 gttgtgatgc tatcatgact agatgtttag cagtccatga gtgctttgtt aagcgcgttg
18841 attggtctgt tgaataccct attataggag atgaactgag ggttaattct gcttgcagaa
18901 aagtacaaca catggttgtg aagtctgcat tgcttgctga taagtttcca gttcttcatg
18961 acattggaaa tccaaaggct atcaagtgtg tgcctcaggc tgaagtagaa tggaagttct
19021 acgatgctca gccatgtagt gacaaagctt acaaaataga ggaactcttc tattcttatg
19081 ctacacatca cgataaattc actgatggtg tttgtttgtt ttggaattgt aacgttgatc
19141 gttacccagc caatgcaatt gtgtgtaggt ttgacacaag agtcttgtca aacttgaact
19201 taccaggctg tgatggtggt agtttgtatg tgaataagca tgcattccac actccagctt
19261 tcgataaaag tgcatttact aatttaaagc aattgccttt cttttactat tctgatagtc
19321 cttgtgagtc tcatggcaaa caagtagtgt cggatattga ttatgttcca ctcaaatctg
19381 ctacgtgtat tacacgatgc aatttaggtg gtgctgtttg cagacaccat gcaaatgagt
19441 accgacagta cttggatgca tataatatga tgatttctgc tggatttagc ctatggattt
19501 acaaacaatt tgatacttat aacctgtgga atacatttac caggttacag agtttagaaa
19561 atgtggctta taatgttgtt aataaaggac actttgatgg acacgccggc gaagcacctg

19621 tttccatcat taataatgct gtttacacaa aggtagatgg tattgatgtg gagatctttg
19681 aaaataagac aacacttcct gttaatgttg catttgagct ttgggctaag cgtaacatta
19741 aaccagtgcc agagattaag atactcaata atttgggtgt tgatatcgct gctaatactg
19801 taatctggga ctacaaaaga gaagccccag cacatgtatc tacaataggt gtctgcacaa
19861 tgactgacat tgccaagaaa cctactgaga gtgcttgttc ttcacttact gtcttgtttg
19921 atggtagagt ggaaggacag gtagaccttt ttagaaacgc ccgtaatggt gttttaataa
19981 cagaaggttc agtcaaaggt ctaacacctt caaagggacc agcacaagct agcgtcaatg
20041 gagtcacatt aattggagaa tcagtaaaaa cacagtttaa ctactttaag aaagtagacg
20101 gcattattca acagttgcct gaaacctact ttactcagag cagagactta gaggatttta
20161 agcccagatc acaaatggaa actgactttc tcgagctcgc tatggatgaa ttcatacagc
20221 gatataagct cgagggctat gccttcgaac acatcgttta tggagatttc agtcatggac
20281 aacttggcgg tcttcattta atgataggct tagccaagcg ctcacaagat tcaccactta
20341 aattagagga ttttatccct atggacagca cagtgaaaaa ttacttcata acagatgcgc
20401 aaacaggttc atcaaaatgt gtgtgttctg tgattgatct tttacttgat gactttgtcg
20461 agataataaa gtcacaagat ttgtcagtga tttcaaaagt ggtcaaggtt acaattgact
20521 atgctgaaat ttcattcatg ctttggtgta aggatggaca tgttgaaacc ttctacccaa
20581 aactacaagc aagtcgagcg tggcaaccag gtgttgcgat gcctaacttg tacaagatgc
20641 aaagaatgct tcttgaaaag tgtgaccttc agaattatgg tgaaaatgct gttataccaa
20701 aaggaataat gatgaatgtc gcaaagtata ctcaactgtg tcaatactta aatacactta
20761 ctttagctgt accctacaac atgagagtta ttcactttgg tgctggctct gataaaggag
20821 ttgcaccagg tacagctgtg ctcagacaat ggttgccaac tggcacacta cttgtcgatt
20881 cagatcttaa tgacttcgtc tccgacgcat attctacttt aattggagac tgtgcaacag
20941 tacatacggc taataaatgg gaccttatta ttagcgatat gtatgaccct aggaccaaac
21001 atgtgacaaa agagaatgac tctaaagaag ggtttttcac ttatctgtgt ggatttataa
21061 agcaaaaact agccctgggt ggttctatag ctgtaaagat aacagagcat tcttggaatg
21121 ctgaccttta caagcttatg ggccatttct catggtggac agcttttgtt acaaatgtaa
21181 atgcatcatc atcggaagca tttttaattg gggctaacta tcttggcaag ccgaaggaac
21241 aaattgatgg ctataccatg catgctaact acattttctg gaggaacaca aatcctatcc
21301 agttgtcttc ctattcactc tttgacatga gcaaatttcc tcttaaatta agaggaactg
21361 ctgtaatgtc tcttaaggag aatcaaatca atgatatgat ttattctctt ctggaaaaag
21421 gtaggcttat cattagagaa aacaacagag ttgtggtttc aagtgatatt cttgttaaca
21481 actaaacgaa catgtttatt ttcttattat ttcttactct cactagtggt agtgaccttg
21541 accggtgcac cacttttgat gatgttcaag ctcctaatta cactcaacat acttcatcta
21601 tgaggggggt ttactatcct gatgaaattt ttagatcaga cactctttat ttaactcagg
21661 atttatttct tccattttat tctaatgtta cagggtttca tactattaat catacgtttg
21721 gcaaccctgt catacctttt aaggatggta tttattttgc tgccacagag aaatcaaatg
21781 ttgtccgtgg ttgggttttt ggttctacca tgaacaacaa gtcacagtcg gtgattatta
21841 ttaacaattc tactaatgtt gttatacgag catgtaactt tgaattgtgt gacaaccctt
21901 tctttgctgt ttctaaaccc atgggtacac agacacatac tatgatattc gataatgcat
21961 ttaattgcac tttcgagtac atatctgatg ccttttcgct tgatgtttca gaaaagtcag
22021 gtaattttaa acacttacga gagtttgtgt ttaaaaataa agatgggttt ctctatgttt
22081 ataagggcta tcaacctata gatgtagttc gtgatctacc ttctggtttt aacactttga
22141 aacctatttt taagttgcct cttggtatta acattacaaa ttttagagcc attcttacag
22201 ccttttcacc tgctcaagac atttggggca cgtcagctgc agcctatttt gttggctatt
22261 taaagccaac tacatttatg ctcaagtatg atgaaaatgg tacaatcaca gatgctgttg
22321 attgttctca aaatccactt gctgaactca aatgctctgt taagagcttt gagattgaca
22381 aaggaattta ccagacctct aatttcaggg ttgttccctc aggagatgtt gtgagattcc
22441 ctaatattac aaacttgtgt ccttttggag aggtttttaa tgctactaaa ttcccttctg
22501 tctatgcatg ggagagaaaa aaaatttcta attgtgttgc tgattactct gtgctctaca
22561 actcaacatt ttttcaacc tttaagtgct atggcgtttc tgccactaag ttgaatgatc
22621 tttgcttctc caatgtctat gcagattctt ttgtagtcaa gggagatgat gtaagacaaa
22681 tagcgccagg acaaactggt gttattgctg attataatta taaattgcca gatgatttca
22741 tgggttgtgt ccttgcttgg aatactagga acattgatgc tacttcaact ggtaattata
22801 attataaata taggtatctt agacatggca agcttaggcc ctttgagaga gacatatcta
22861 atgtgccttt ctcccctgat ggcaaacctt gcaccccacc tgctcttaat tgttattggc
22921 cattaaatga ttatggtttt tacaccacta ctggcattgg ctaccaacct tacagagttg

22981 tagtactttc ttttgaactt ttaaatgcac cggccacggt ttgtggacca aaattatcca
23041 ctgaccttat taagaaccag tgtgtcaatt ttaattttaa tggactcact ggtactggtg
23101 tgttaactcc ttcttcaaag agatttcaac catttcaaca atttggccgt gatgtttctg
23161 atttcactga ttccgttcga gatcctaaaa catctgaaat attagacatt tcaccttgcg
23221 cttttggggg tgtaagtgta attacacctg gaacaaatgc ttcatctgaa gttgctgttc
23281 tatatcaaga tgttaactgc actgatgttt ctacagcaat tcatgcagat caactcacac
23341 cagcttggcg catatattct actggaaaca atgtattcca gactcaagca ggctgtctta
23401 taggagctga gcatgtcgac acttcttatg agtgcgacat tcctattgga gctggcattt
23461 gtgctagtta ccatacagtt tctttattac gtagtactag ccaaaaatct attgtggctt
23521 atactatgtc tttaggtgct gatagttcaa ttgcttactc taataacacc attgctatac
23581 ctactaactt ttcaattagc attactacag aagtaatgcc tgtttctatg gctaaaacct
23641 ccgtagattg taatatgtac atctgcggag attctactga atgtgctaat ttgcttctcc
23701 aatatggtag cttttgcaca caactaaatc gtgcactctc aggtattgct gctgaacagg
23761 atcgcaacac acgtgaagtg ttcgctcaag tcaaacaaat gtacaaaacc ccaactttga
23821 aatattttgg tggttttaat ttttcacaaa tattacctga ccctctaaag ccaactaaga
23881 ggtcttttat tgaggacttg ctctttaata aggtgacact cgctgatgct ggcttcatga
23941 agcaatatgg cgaatgccta ggtgatatta atgctagaga tctcatttgt gcgcagaagt
24001 tcaatggact tacagtgttg ccacctctgc tcactgatga tatgattgct gcctacactg
24061 ctgctctagt tagtggtact gccactgctg gatggacatt tggtgctggc gctgctcttc
24121 aaataccttt tgctatgcaa atggcatata ggttcaatgg cattggagtt acccaaaatg
24181 ttctctatga gaaccaaaaa caaatcgcca accaatttaa caaggcgatt agtcaaattc
24241 aagaatcact tacaacaaca tcaactgcat tgggcaagct gcaagacgtt gttaaccaga
24301 atgctcaagc attaaacaca cttgttaaac aacttagctc taattttggt gcaatttcaa
24361 gtgtgctaaa tgatatcctt tcgcgacttg ataaagtcga ggcggaggta caaattgaca
24421 ggttaattac aggcagactt caaagccttc aaacctatgt aacacaacaa ctaatcaggg
24481 ctgctgaaat cagggcttct gctaatcttg ctgctactaa aatgtctgag tgtgttcttg
24541 gacaatcaaa aagagttgac ttttgtggaa agggctacca ccttatgtcc ttcccacaag
24601 cagccccgca tggtgttgtc ttcctacatg tcacgtatgt gccatcccag gagaggaact
24661 tcaccacagc gccagcaatt tgtcatgaag gcaaagcata cttccctcgt gaaggtgttt
24721 ttgtgtttaa tggcacttct tggtttatta cacagaggaa cttcttttct ccacaaataa
24781 ttactacaga caatacattt gtctcaggaa attgtgatgt cgttattggc atcattaaca
24841 acacagttta tgatcctctg caacctgagc ttgactcatt caaagaagag ctggacaagt
24901 acttcaaaaa tcatacatca ccagatgttg atcttggcga catttcaggc attaacgctt
24961 ctgtcgtcaa cattcaaaaa gaaattgacc gcctcaatga ggtcgctaaa aatttaaatg
25021 aatcactcat tgaccttcaa gaattgggaa aatatgagca atatattaaa tggccttggt
25081 atgtttggct cggcttcatt gctggactaa ttgccatcgt catggttaca atcttgcttt
25141 gttgcatgac tagttgttgc agttgcctca agggtgcatg ctcttgtggt tcttgctgca
25201 agtttgatga ggatgactct gagccagttc tcaagggtgt caaattacat tacacataaa
25261 cgaacttatg gatttgttta tgagattttt tactcttgga tcaattactg cacagccagt
25321 aaaaattgac aatgcttctc ctgcaagtac tgttcatgct acagcaacga taccgctaca
25381 agcctcactc cctttcggat ggcttgttat tggcgttgca tttcttgctg tttttcagag
25441 cgctaccaaa ataattgcgc tcaataaaag atggcagcta gcccttttata agggcttcca
25501 gttcatttgc aatttactgc tgctatttgt taccatctat tcacatcttt tgcttgtcgc
25561 tgcaggtatg gaggcgcaat ttttgtacct ctatgccttg atatattttc tacaatgcat
25621 caacgcatgt agaattatta tgagatgttg gctttgttgg aagtgcaaat ccaagaaccc
25681 attactttat gatgccaact actttgtttg ctggcacaca cataactatg actactgtat
25741 accatataac agtgtcacag atacaattgt cgttactgaa ggtgacggca tttcaacacc
25801 aaaactcaaa gaagactacc aaattggtgg ttattctgag gataggcact caggtgttaa
25861 agactatgtc gttgtacatg gctatttcac cgaagtttac taccagcttg agtctacaca
25921 aattactaca gacactggta ttgaaaatgc tacattcttc atctttaaca agcttgttaa
25981 agacccaccg aatgtgcaaa tacacacaat cgacggctct tcaggagttg ctaatccagc
26041 aatggatcca atttatgatg agccgacgac gactactagc gtgcctttgt aagcacaaga
26101 aagtgagtac gaacttatgt actcattcgt ttcggaagaa acaggtacgt taatagttaa
26161 tagcgtactt ctttttcttg ctttcgtggt attcttgcta gtcacactag ccatccttac
26221 tgcgcttcga ttgtgtgcgt actgctgcaa tattgttaac gtgagtttag taaaaccaac
26281 ggtttacgtc tactcgcgtg ttaaaaatct gaactcttct gaaggagttc ctgatcttct

26341 ggtctaaacg aactaactat tattattatt ctgtttggaa ctttaacatt gcttatcatg
26401 gcagacaacg gtactattac cgttgaggag cttaaacaac tcctggaaca atggaaccta
26461 gtaataggtt tcctattcct agcctggatt atgttactac aatttgccta ttctaatcgg
26521 aacaggtttt tgtacataat aaagcttgtt ttcctctggc tcttgtggcc agtaacactt
26581 gcttgttttg tgcttgctgc tgtctacaga attaattggg tgactggcgg gattgcgatt
26641 gcaatggctt gtattgtagg cttgatgtgg cttagctact tcgttgcttc cttcaggctg
26701 tttgctcgta cccgctcaat gtggtcattc aacccagaaa caaacattct tctcaatgtg
26761 cctctccggg ggacaattgt gaccagaccg ctcatggaaa gtgaacttgt cattggtgct
26821 gtgatcattc gtggtcactt gcgaatggcc ggacactccc tagggcgctg tgacattaag
26881 gacctgccaa aagagatcac tgtggctaca tcacgaacgc tttcttatta caaattagga
26941 gcgtcgcagc gtgtaggcac tgattcaggt tttgctgcat acaaccgcta ccgtattgga
27001 aactataaat taaatacaga ccacgccggt agcaacgaca atattgcttt gctagtacag
27061 taagtgacaa cagatgtttc atcttgttga cttccaggtt acaatagcag agatattgat
27121 tatcattatg aggactttca ggattgctat ttggaatctt gacgttataa taagttcaat
27181 agtgagacaa ttatttaagc ctctaactaa gaagaattat tcggagttag atgatgaaga
27241 acctatggag ttagattatc cataaaacga acatgaaaat tattctcttc ctgacattga
27301 ttgtatttac atcttgcgag ctatatcact atcaggagtg tgttagaggt acgactgtac
27361 tactaaaaga accttgccca tcaggaacat acgagggcaa ttcaccattt caccctcttg
27421 ctgacaataa atttgcacta acttgcacta gcacacactt tgcttttgct tgtgctgacg
27481 gtactcgaca tacctatcag ctgcgtgcaa gatcagtttc accaaaactt ttcatcagac
27541 aagaggaggt tcaacaagag ctctactcgc cacttttct cattgttgct gctctagtat
27601 ttttaatact ttgcttcacc attaagagaa agacagaatg aatgagctca ctttaattga
27661 cttctatttg tgctttttag cctttctgct attccttgtt ttaataatgc ttattatatt
27721 ttggttttca ctcgaaatcc aggatctaga agaaccttgt accaaagtct aaacgaacat
27781 gaaacttctc attgttttga cttgtatttc tctatgcagt tgcatatgca ctgtagtaca
27841 gcgctgtgca tctaataaac ctcatgtgct tgaagatcct tgtaaggtac aacactaggg
27901 gtaatactta tagcactgct tggctttgtg ctctaggaaa ggttttacct tttcatagat
27961 ggcacactat ggttcaaaca tgcacaccta atgttactat caactgtcaa gatccagctg
28021 gtggtgcgct tatagctagg tgttggtacc ttcatgaagg tcaccaaact gctgcattta
28081 gagacgtact tgttgtttta aataaacgaa caaattaaaa tgtctgataa tggaccccaa
28141 tcaaaccaac gtagtgcccc ccgcattaca tttggtggac ccacagattc aactgacaat
28201 aaccagaatg gaggacgcaa tggggcaagg ccaaaacagc gccgacccca aggtttaccc
28261 aataatactg cgtcttggtt cacagctctc actcagcatg gcaaggagga acttagattc
28321 cctcgaggcc agggcgttcc aatcaacacc aatagtggtc cagatgacca aattggctac
28381 taccgaagag ctacccgacg agttcgtggt ggtgacggca aaatgaaaga gctcagcccc
28441 agatggtact tctattacct aggaactggc ccagaagctt cacttcccta cggcgctaac
28501 aaagaaggca tcgtatgggt tgcaactgag ggagccttga atacacccaa agaccacatt
28561 ggcacccgca atcctaataa caatgctgcc accgtgctac aacttcctca aggaacaaca
28621 ttgccaaaag gcttctacgc agagggaagc agaggcggca gtcaagcctc ttctcgctcc
28681 tcatcacgta gtcgcggtaa ttcaagaaat tcaactcctg gcagcagtag gggaaattct
28741 cctgctcgaa tggctagcgg aggtggtgaa actgccctcg cgctattgct gctagacaga
28801 ttgaaccagc ttgagagcaa agtttctggt aaaggccaac aacaacaagg ccaaactgtc
28861 actaagaaat ctgctgctga ggcatctaaa aagcctcgcc aaaaacgtac tgccacaaaa
28921 cagtacaacg tcactcaagc atttgggaga cgtggtccag aacaaaccca aggaaatttc
28981 ggggaccaag acctaatcag acaaggaact gattacaaac attggccgca aattgcacaa
29041 tttgctccaa gtgcctctgc attctttgga atgtcacgca ttggcatgga agtcacacct
29101 tcgggaacat ggctgactta tcatggagcc attaaattgg atgacaaaga tccacaattc
29161 aaagacaacg tcatactgct gaacaagcac attgacgcat acaaaacatt cccaccaaca
29221 gagcctaaaa aggacaaaaa gaaaaagact gatgaagctc agcctttgcc gcagagacaa
29281 aagaagcagc ccactgtgac tcttcttcct gcggctgaca tggatgattt ctccagacaa
29341 cttcaaaatt ccatgagtgg agcttctgct gattcaactc aggcataaac actcatgatg
29401 accacacaag gcagatgggc tatgtaaacg ttttcgcaat tccgtttacg atacatagtc
29461 tactcttgtg cagaatgaat tctcgtaact aaacagcaca agtaggttta gttaacttta
29521 atctcacata gcaatcttta atcaatgtgt aacattaggg aggacttgaa agagccacca
29581 cattttcatc gaggccacgc ggagtacgat cgagggtaca gtgaataatg ctagggagag
29641 ctgcctatat ggaagagccc taatgtgtaa aattaatttt agtagtgcta tccccatgtg

29701 attttaatag cttcttagga gaatgacaaa aaaaaaaaaa aaaaaaaaaa a
//

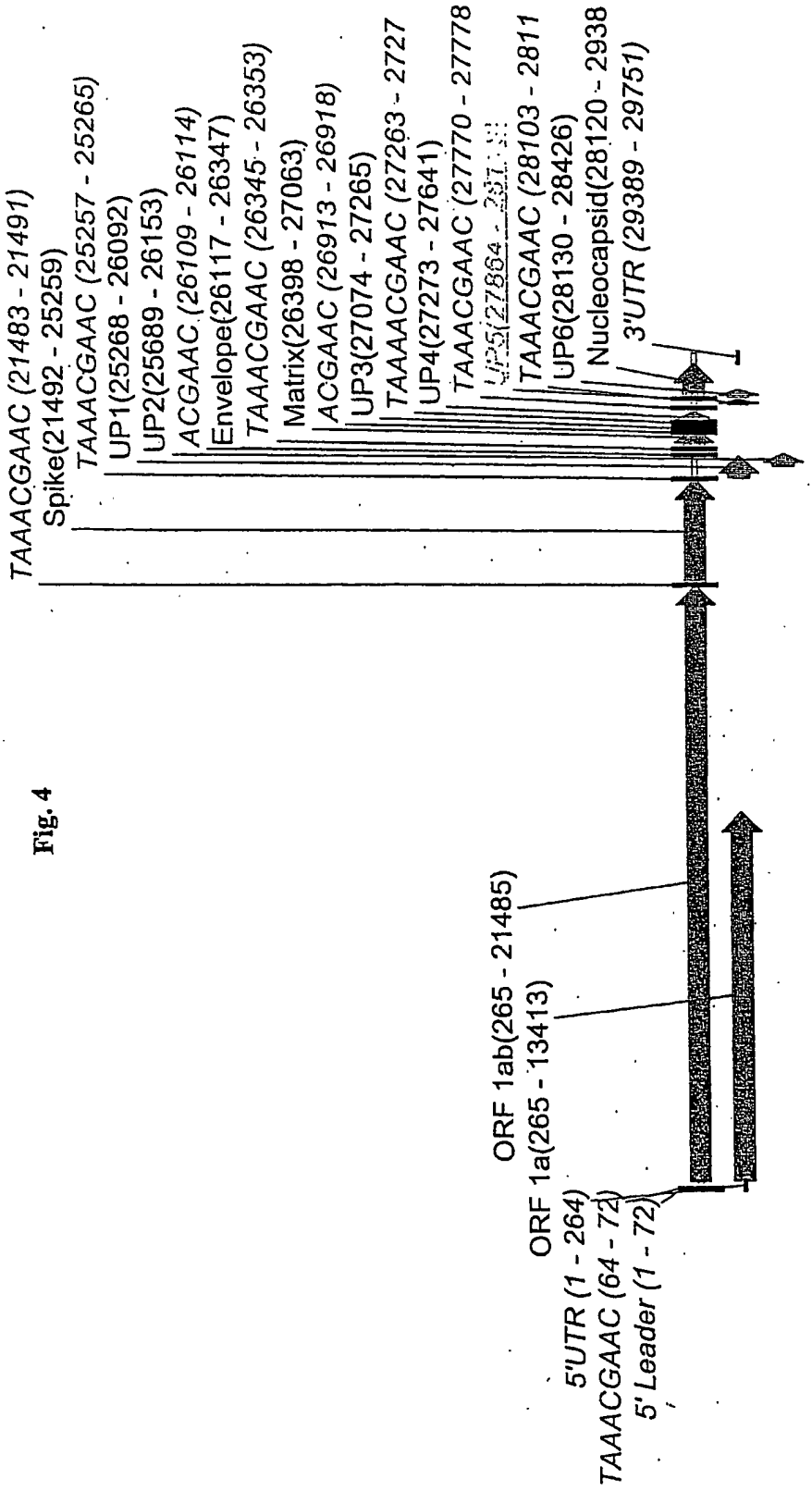
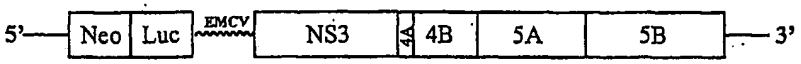


Fig. 4

Fig. 5. The Subgenomic HCV Replicon Used to Test The Efficacy of siRNA in Human Liver Cells



Neo: neomycin phosphotransferase gene

Luc: fruit fly luciferase

EMCV: internal ribosome entry site taken from EMCV

NS3, NS4A, NS4B, NS5A, and NS5B: HCV nonstructural proteins

Fig. 6. The Effect of siRNA$_5$ on HCV Replication In Huh 5-2 Cells

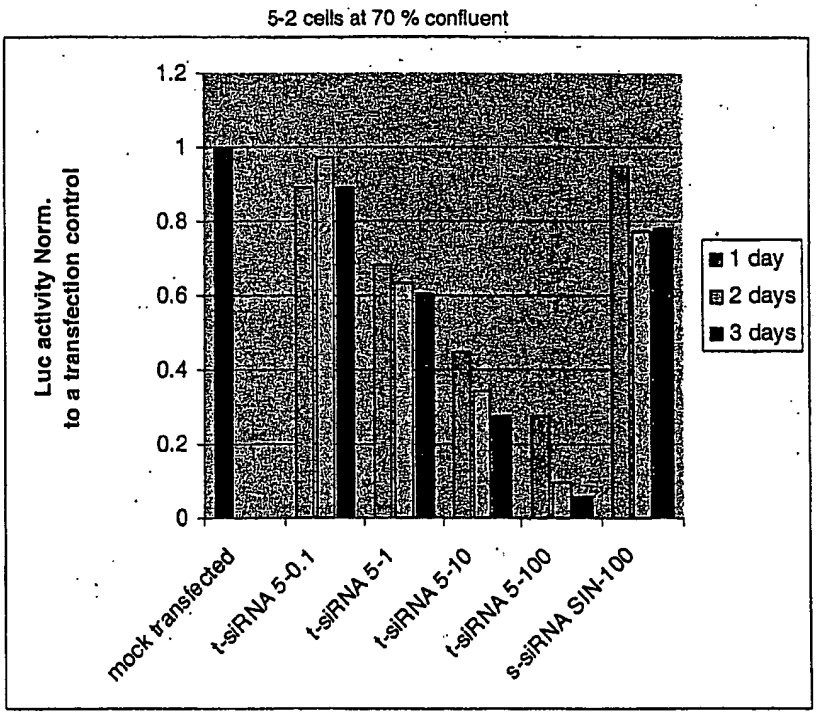


Fig. 7. Sequence Specificity Required for Mediating RNA Interference in Huh7 Cells

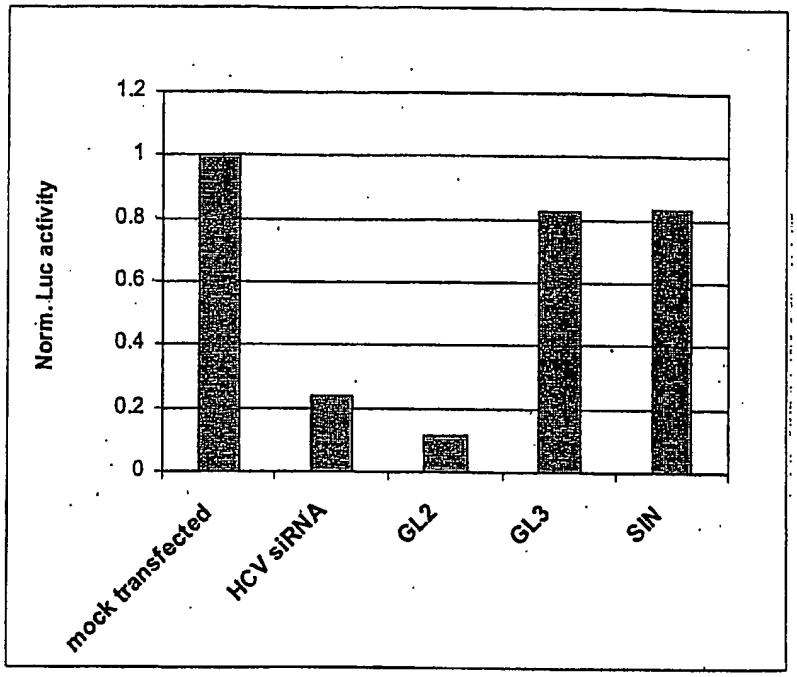


Fig. 8. The Effect of siRNA5 of Cell Viability Measured by Cellular ATPase Activity

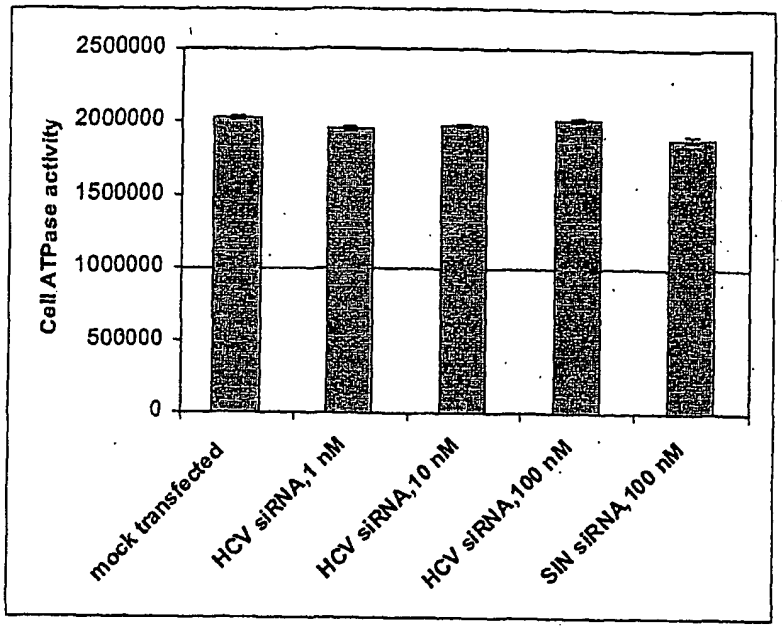


Fig. 9. The Effect of $siRNA_5$ on HCV Replication in Huh-7 Cells Measured by HCV RNA Assay

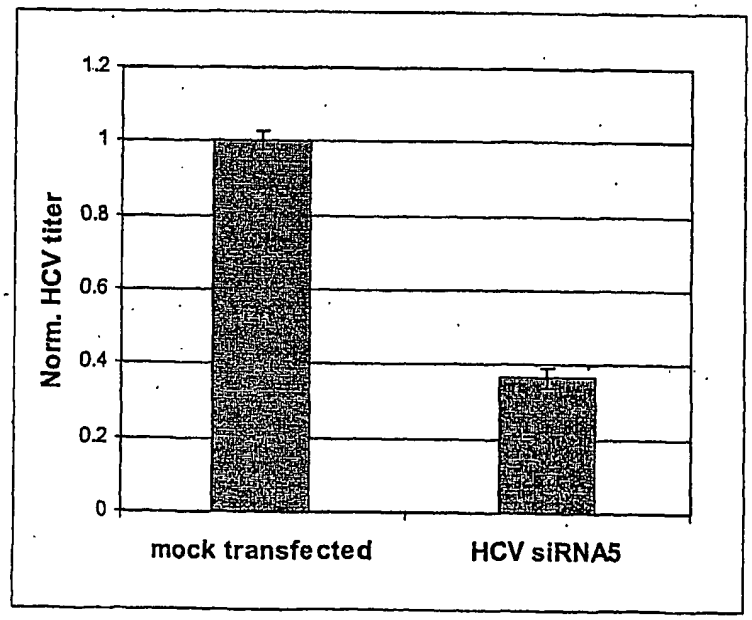


Fig. 10

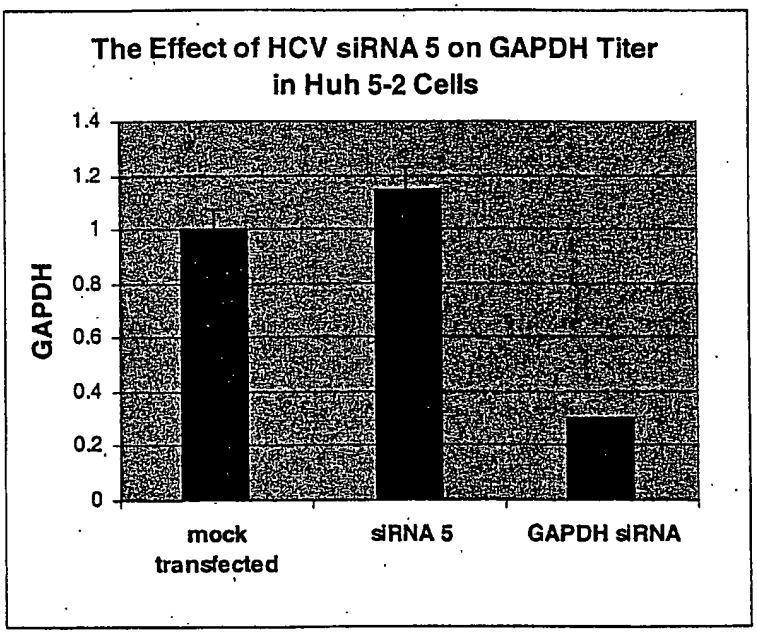


Fig. 11

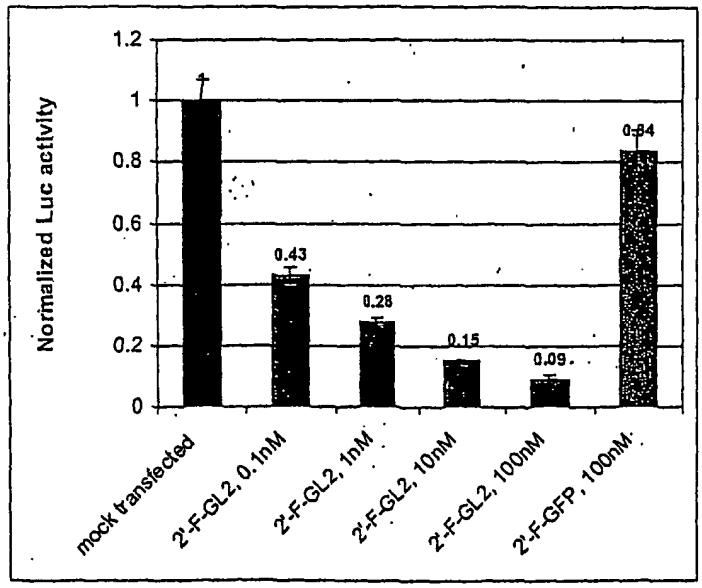


Fig. 12

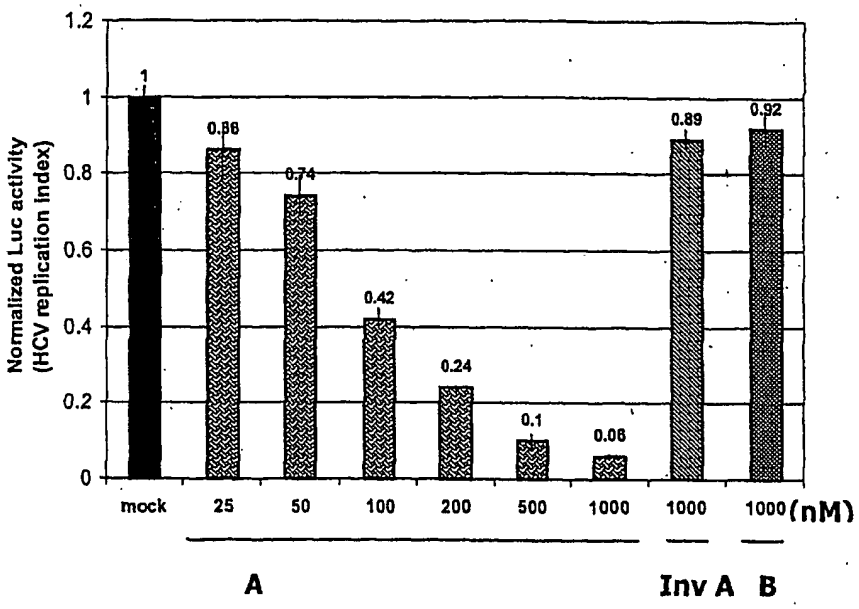


Fig. 13

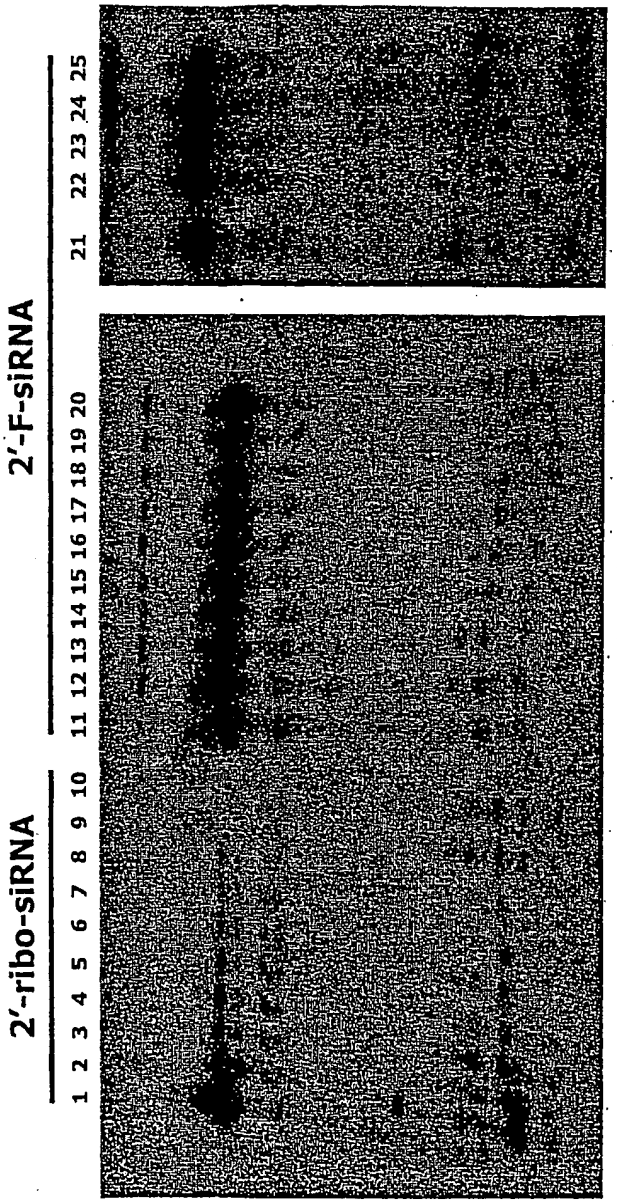
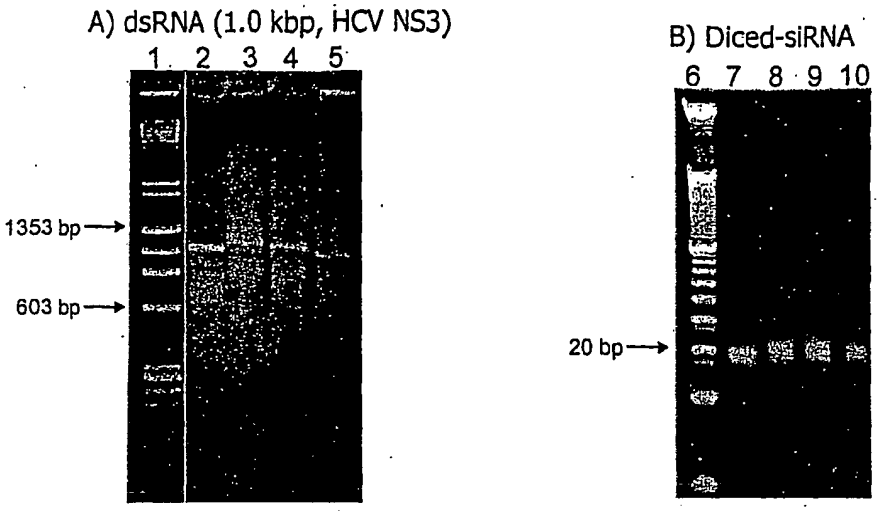


Fig. 14



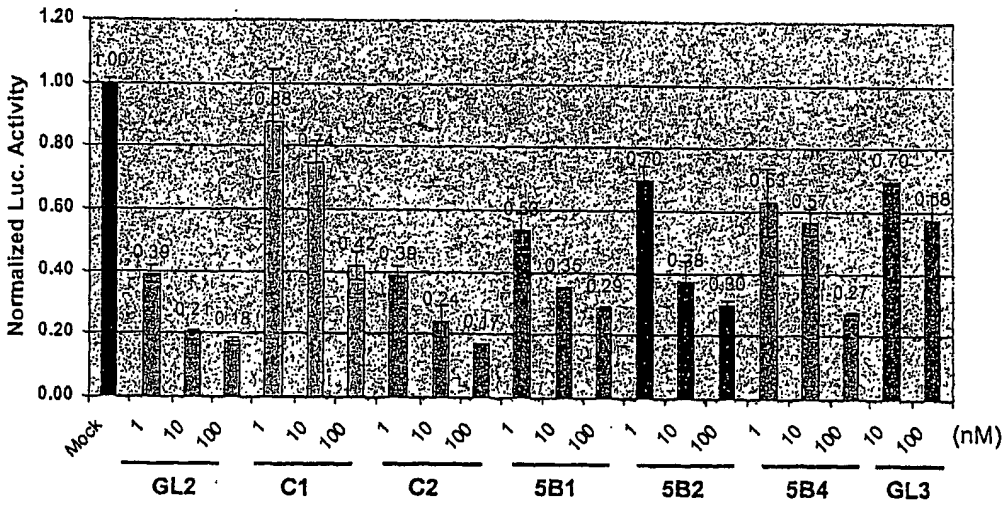


Fig. 15

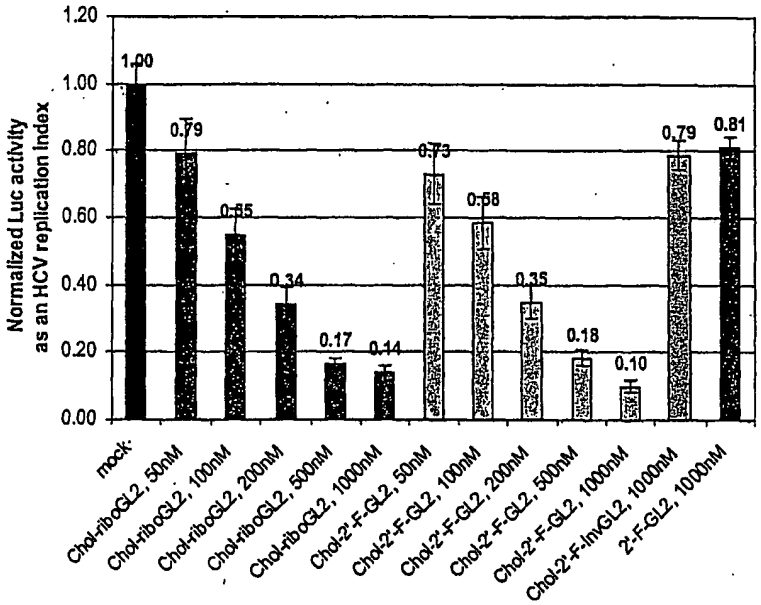


Fig. 16